DOCUMENTED BRIEFING

RAND

Army Air and Missile Defense

Future Challenges

Frances M. Lussier, Michael D. Miller, Brian Nichiporuk. David C. McGarvey, Lowell Schwartz, David Vaughan

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Prepared for the
United States Army

Arroyo Center

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PREFACE

This documented briefing represents the results of work done on the "Army Air and Missile Defense: Future Challenges" project for MG Dennis D. Cavin, Commander of the Air Defense Artillery Center and Fort Bliss, Tex. The effort was intended to help focus the Army's research and development efforts by providing insights into the future needs for air and missile defense. This research should be of interest to defense planners and policymakers, concept and materiel developers, and acquisition executives.

The study was undertaken within the Force Development and Technology Program of RAND's Arroyo Center, a federally funded research and development center sponsored by the U.S. Army.

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SUMMARY

The Army must take steps today if it is to provide effective air and missile defenses against the threats that will emerge 20 years hence. Most analysts predict that the globalization of the economy means that existing and new technologies will become increasingly available worldwide and that many sophisticated weapons will be easier and cheaper to produce or acquire. But trends in the international political sphere are harder to identify. The international arena has seen such flux in the past two decades that it is difficult to predict what changes will occur in the next 20 to 25 years, but they could be substantial.

RAND examined how a wide range of possible trends might shape the future world situation. Doing so, we believe, provides insight into how these trends and accompanying technological changes might influence the Army's plans to develop its air and missile defenses (AMD). We drew on previous RAND work that characterized six possible futures for 2025 to establish a context for Army AMD in the period. Representative scenarios for each of these futures provided a means for illustrating how differing geopolitical or strategic situations might influence air and missile defense requirements for the future. We used the six scenarios to identify potential AMD shortfalls or redundancies in various settings and, consequently, those areas where the Army might best focus its research and development (R&D) efforts.

One conclusion that we draw from our analysis is that the threat of cruise missile attack, and the need to defend against it, is present in all futures and scenarios. Although large numbers of cruise missiles or ones based on sophisticated technology are likely to be present only in those scenarios that include conventional conflict, unsophisticated versions based on unmanned aerial vehicles (UAVs) could be present in small numbers in any scenario. And, regardless of the type of operation, the U.S. military will need early access to airports that can be threatened by even unsophisticated cruise missiles that could be available to drug lords and terrorists. In some circumstances, very large and densely populated areas may be at risk from cruise missile attack. Indeed, much of the continental United States (CONUS) was at such risk in one scenario.

Because cruise missiles and UAVs are universal threats, short-range air defenses (SHORAD) will also be needed to defend against weapons that make it through the outer layers. In those cases where manned aircraft are likely to be present, SHORAD systems can degrade the enemy's ability to attack U.S. and allied assets effectively by forcing enemy ground-attack aircraft to higher altitudes or by

denying the enemy information gathered by UAVs. Rockets and mortars were also present in all scenarios considered, and destroying them in the air would be desirable. However, developing such a capability might not be worth the investment if other approaches, such as counterbattery fire, are effective in dealing with these threats.

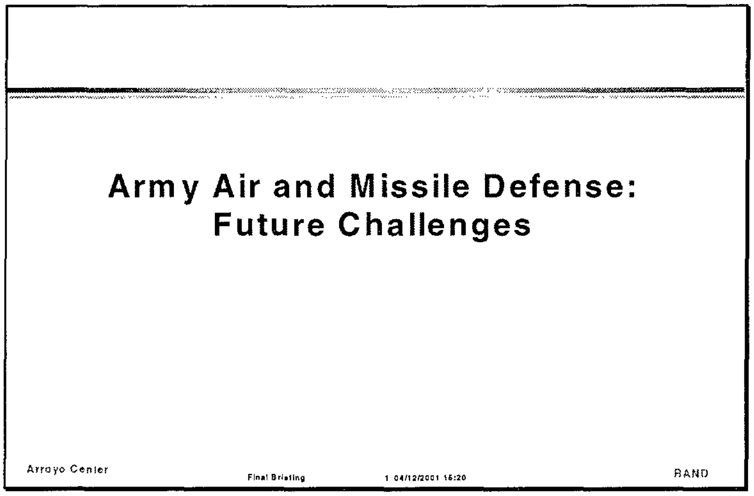
In contrast, the need for defense against theater ballistic missiles (TBMs) depends on the likelihood of conventional war in the future. If the world evolves to the state where such war is unlikely, the need for TBM defenses is not high. Nevertheless, until it becomes clear that the future is evolving in a way that makes it unlikely that the United States would be involved in conflicts with rogue states or a peer competitor, TBM defenses will be needed in theater during the initial stages of the operation. Because no single system fielded by any of the services can defend all assets in theater from all likely threats, Army as well as Navy systems are needed early. Indeed, once Army antitactical ballistic missile (ATBM) systems arrive in theater, they provide some unique capabilities. These include the ability to protect inland areas, as well as an autonomous radar with significant detection and tracking capability. Some additional capabilities, however, would enhance the ability of the Army's ATBM systems to perform their mission. One is the ability to accompany ground forces engaged in fast-paced maneuver operations. The other, which would be needed if the future world that envisions a peer competitor becomes a reality, is the capability to defeat large and sustained barrage attacks of TBMs.

When compared with the current and postulated AMD systems, these requirements then lead to the identification of R&D efforts that should be emphasized. The Army should place increased emphasis on providing defense against cruise missiles because it will be needed whatever the world looks like 20 years from now. To ensure that those defenses are effective, the Army needs to develop a balloon- or aircraft-mounted system capable of detecting low-altitude cruise missiles at long range. Assuming that naval systems would be available to defend seaports, the Army should concentrate on making its cruise missile defenses deployable so they will be available to protect airports that are crucial to the opening of a theater. Finally, to provide for the defense of CONUS or other large territories, effort should be invested in developing long-range interceptors so that cruise missile defenses can protect large geographic areas with a reasonable number of launchers.

To field SHORAD systems capable against the variety of threats likely in a wide range of futures, the Army should develop complementary systems. There remains a need to retain large numbers of SHORAD systems with capability against manned aircraft. Laser systems seem to have the potential to defeat threats that missiles cannot—rockets, artillery, and mortars. However, laser technology is still immature, and fielding an effective weapon will require

technological breakthroughs that are not guaranteed to occur. Thus, as a hedge against failing to obtain those breakthroughs, it would be wise to continue investigating improvements to the resistance of SHORAD missiles to countermeasures, as well as ways to make laser weapons feasible.

Finally, with respect to defenses against TBMs, the Army may want to wait until trends that will define the future become more evident before significantly increasing its investment in such systems. If the emergence of a near-peer competitor makes the world more dangerous, then the Army will need to develop very effective interceptors and launchers with large numbers of ready rounds to counter large-barrage missile attacks. Even if such a future world does not develop, however, the Army should investigate ways to further enhance its anti-TBM systems. It needs to develop smaller and more-efficient radars and generators to make the Theater High-Altitude Area Defense system (THAAD) more easily deployable and supportable. Also, the Army needs to develop a mobile or easily transportable system capable of keeping up with fast-paced operations.



This documented briefing marks the final report for the Army Air and Missile Defense project, which began in March 1999 under the sponsorship of MG Dennis D. Cavin, Commanding General of the U.S. Army Air Defense Artillery Center and Fort Bliss, Tex. This briefing, therefore, presents the results of the project's efforts.

Study Background

- Army must direct R&D efforts today to meet the AMD challenge in 2020
- What we do know:
  - Technology will continue to evolve
  - Some technologies will decrease in cost
  - Many technologies will become more available
  - Fielded systems will rapidly become obsolete
- What we do not know: how economic, demographic, political, and other trends will shape world
- Examining AMD in a range of alternative futures may provide insights not available from analysis tied to a single vision of the future

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The motivation for the project is the Army's need to initiate research and development (R&D) efforts today to meet challenges it might face 20 years from now. It is relatively certain that existing and new technologies will become increasingly available worldwide and that many sophisticated weapons will be easier and cheaper for potential enemies to produce or acquire. But considerable uncertainty exists regarding trends in the international sphere. Because the international arena has seen such flux in the past two decades, it is difficult to predict what, if any, changes will occur in the next 20 years. This uncertainty could make positioning the Army for the next 20 to 30 years difficult.

The study examined how a wide range of possible trends might shape the future world situation. Doing so, we believe, can provide insight about how these trends and accompanying technological changes might influence the Army's strategies for its Air and Missile Defenses (AMD).

Study Plan

- **Establish context**
  - **Characterize possible futures drawing on previous RAND work and identify representative scenarios and describe likely U.S. operations**
  - **Illustrate how geographic and strategic situations might affect AMD requirements in 2015–2025**
- **Identify opportunities for Army AMD**
- **Identify issues concerning the provision of various types of AMD**
- **Assess the potential of currently proposed systems**
- **Identify areas where Army AMD R&D efforts might be focused**

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This chart describes how we have conducted our analysis of what AMD might entail in the future. First we established a context for Army AMD in the period from 2015 to 2025 by drawing on previous RAND work that characterized several possible futures for that time frame and identified representative scenarios for each of the futures. Using those scenarios to illustrate how differing geopolitical or strategic situations might influence AMD requirements for the future, we have identified opportunities for Army AMD and issues concerning provision of AMD in widely varied settings. After assessing the potential of currently proposed systems to provide AMD under varying circumstances, we identified those areas where the Army might best focus its R&D efforts.

Briefing Outline

- Description of possible future worlds and representative scenarios
- Assessment of AMD priorities for U.S. military in future worlds
- Analysis of defense against different classes of threat
- Identification of potential areas of future R&D effort

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This briefing is divided into four sections. The first describes six possible worlds envisioned for 2025 and associated illustrative scenarios. The next section presents an assessment of the relative importance of several AMD tasks in each of the illustrative scenarios. Following that is an analysis of issues concerning the provision of AMD against the different classes of threats present in our scenarios. The final section includes a discussion of the areas where the Army might focus its R&D efforts to provide a more robust AMD in the future.

RAND Research Into Future Worlds

- Prior research examined what the world might look like in 2025 and beyond
  - Examined trends in five areas: Demographics, Geopolitics, Economics, Technology, and Environment
  - Combined outcomes (good/medium/bad) for each area to produce six alternative futures
- This effort extended that research to determine what alternative worlds might imply for Army AMD missions

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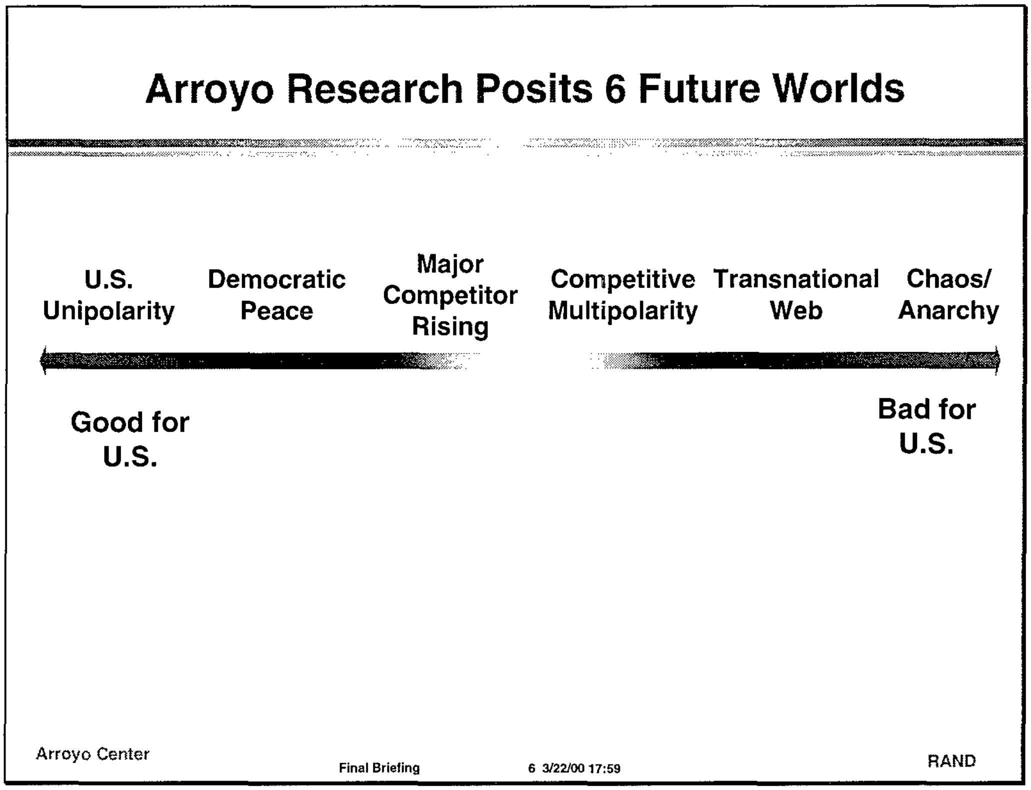
In an attempt to set the stage for 2015–2025, the project turned to previous RAND research that examined future worlds and the implications of those worlds for the Army. This work, initiated by MG Ronald E. Adams, then Assistant Chief of Staff for Operations and Plans for Force Development, examined what the world might look like in 2025.[1] In that work, the researchers strove to avoid making predictions about which worlds the future seems most likely to bring. Rather, they examined trends in five areas listed in recent versions of the Army's Strategic Planning Guidance: demographics, geopolitics, economics, technology, and the environment. The researchers then ranked the trends based on which would yield good, bad, or medium outcomes for U.S. interests for each of those variables. Finally, they combined good outcomes for all of the variables to get two worlds deemed the most favorable for U.S. interests. Similarly, combining all bad trends in the five areas yields the worst possible outcome. Combining medium and good outcomes or medium and bad outcomes leads to the three futures that fill in the range in between. The six worlds extracted from those various combinations cover a broad range of possibilities and were given names associated with current popular headlines.

It should be noted that the relative ranking of the various worlds is not based on military criteria. Rather, the assessment of each future results from the combination of trends in five areas, none of which is tied exclusively to military needs or threat. Although generally related, a future that might be viewed as more or less favorable to U.S. interests because of geopolitical, economic, demographic, technological, and environmental trends, is not necessarily viewed the same way through a military lens. Thus, a world without one great rival but with many smaller anarchic regions might

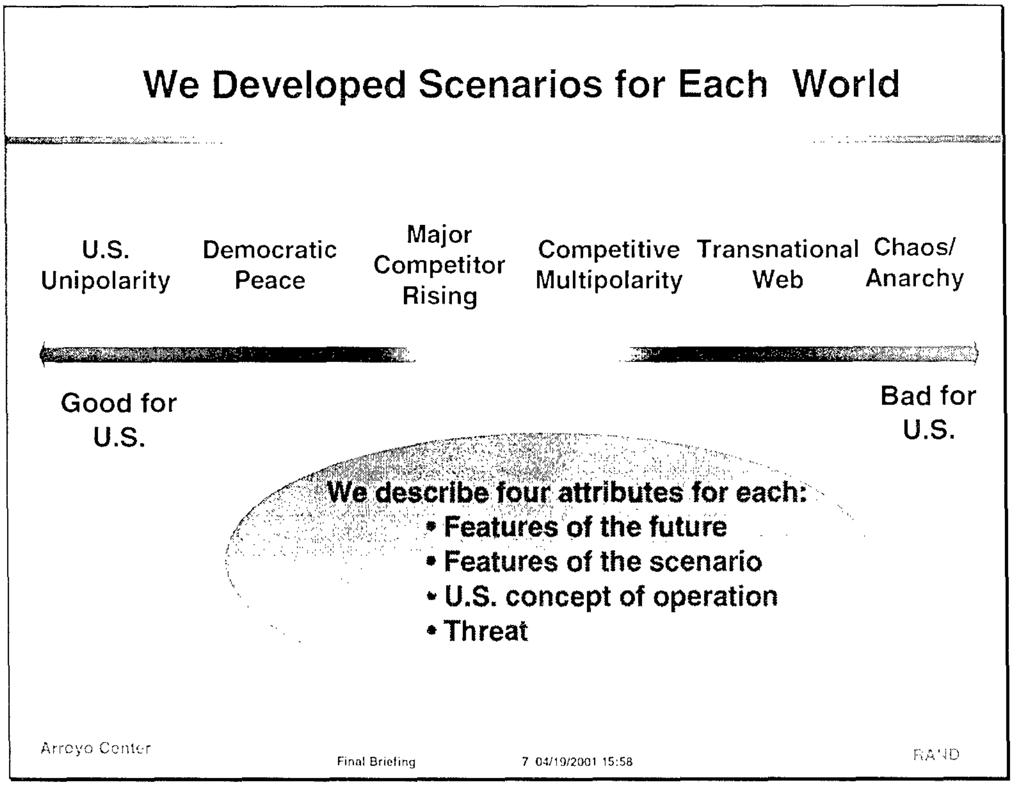
[1]Richard E. Darilek, *Future Army Forces: A Capstone Project's Summary Report*, AB-254-A, RAND, March 1999.

seem to pose less of a military challenge than a world with a peer competitor, but such a world might not be as favorable to U.S. interests overall.

This effort then extrapolated from that research to examine the question of what each of the future worlds might imply for Army AMD.



The six alternative futures that RAND postulates can be pictured along a spectrum that ranges from good to bad as viewed from the overall U.S. perspective. The first two worlds, U.S. Unipolarity and Democratic Peace, are representative of futures that might result if economic, demographic, geopolitical, environmental, and technological trends are all favorable. The last world, Chaos/Anarchy, represents what the future might look like if all the trends are unfavorable. The three worlds in the middle result from trends that are mixed.



The remainder of this section describes each of the six worlds in some detail, including the features of each future, a candidate scenario, the U.S. concept of operations in that scenario, and a brief characterization of the AMD threat in that scenario. Threat characterization includes a list of the types of threat present and an assessment of whether the threat is based on current technology, next-generation technology that might appear in 10 years, or second-generation technology that will not appear for 20 years.

While a variety of scenarios were examined for each of the six future worlds, we have chosen to analyze just one scenario per world. The scenarios chosen were judged the most demanding and stressful for U.S. forces in each of the six worlds. Thus, U.S. military forces capable of dealing with the illustrative scenario would probably be adequate for less challenging operations. And because the demands and conditions vary dramatically from world to world, the resulting collection of six scenarios includes a wide range of the factors important in determining what kind of capabilities the Army would need under varying conditions.

U.S. Unipolarity/ Indonesia Scenario

- Features of this Future
  - United States dominant
  - No challenge from China, Russia, India, or EU
  - Hostile regional powers
  - Sporadic minor peace ops
- Features of Scenario: Indonesian attempt to overrun Malaysian Borneo
  - Light infantry and light armor offensive in rugged terrain
  - Deploy sea mines and fast attack craft
  - Modest stocks of cruise and ballistic missiles (some with chemical warheads)
- U.S. Concept of Operations
  - Attrit Indonesian IADS, C4I, and TELs with air/missile strikes
  - Seize key airports and seaports
  - Create and defend lodgment with airlifted Army forces
  - Counterattack with later arriving heavier Army divisions
- AMD Threat: Current generation missiles, aircraft, UAVs, rocket launchers, artillery, and mortars

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U.S. Unipolarity represents one of the two futures in which all five trends are favorable to U.S. interests. In this case, America remains the globe's only true superpower, continuing to be dominant militarily, economically, politically, and culturally; and neither the distribution of nor the nature of power would have changed appreciably from today. None of the other large powers can challenge America across the board.

This environment would present the United States with two main contingency types. First, it would need to prepare for conflicts against rogue powers using either WMD or asymmetric strategies exploiting niche conventional capabilities. Second, the United States would need to concern itself with minor peace operations in those areas of the developing world wracked by communal violence, famine, or general disorder.

We chose a scenario involving an Indonesian attempt to seize portions of Malaysian territory on Borneo as our illustrative scenario because of the long distance from CONUS to theater and the harsh nature of the local jungle terrain. In this scenario, Indonesia uses its light infantry to attack the Malaysian portion of Borneo, its small Navy to mine and patrol local waters, and its modest stocks of ballistic and cruise missiles to threaten Kuala Lumpur and make U.S. entry into Borneo difficult.

U.S. objectives would be to halt and reverse the Indonesian advance, restore the territorial integrity of Malaysia, and ensure the viability of the existing friendly regime in Kuala Lumpur. To do this, the U.S. military would have to attrit the Indonesian Integrated Air Defense System (IADS), command, control, communications, computers, and intelligence (C4I) system, and missile launchers with attack operations, create and

defend lodgments with initial forces airlifted onto Borneo, and, ultimately, counterattack with heavier ground forces that arrive later.

The AMD threat present in this scenario would include current-generation cruise and ballistic missiles, small numbers of fixed-wing aircraft, reconnaissance UAVs, multiple rocket launchers, artillery, and mortars.

Democratic Peace/
Colombia Scenario

- **Features of this Future**
  - **Spread of democracy eliminates risk of wars**
  - **EU, China, Japan economic, but not political, U.S. rivals**
  - **Social disorder and ethnic violence in parts of the Southern Hemisphere**
  - **Army participation in multinational stabilization operations**
- **Features of Scenario: Urban conflict between rival Colombian drug cartels**
  - **Cease-fire enacted, warring cartels separated**
  - **Deployment of multinational force to enforce cease fire**
- **U.S. Concept of Operations**
  - **Employ light infantry/SF/airmobility to control Bogota buffer zone**
  - **Establish interoperability with allied units**
  - **Disarm cartels, collect intelligence**
  - **Prepare to defeat cartels if cease-fire fails**
- **AMD Threat**
  - **Current generation artillery and mortars**
  - **Next generation weaponized UAVs**

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In our second possible world—Democratic Peace—which, like the first, is based on trends that are all favorable to the United States, we assumed that democracy has taken firm hold in most parts of the world. Unlike the first world, in which democracy is slow to spread and several rogue states still pose challenges to regional security, in this vision of the future all of the world's large and medium powers have come to the conclusion that war is no longer a legitimate instrument of national policy. Thus, although quite different from today's world, this future is no less favorable to the United States than the first.

In this future world, the principal security problems that concern the U.S. military are related to residual disorder existing in those pockets of the world that have not yet adopted or been able to sustain a truly democratic government. These pockets would primarily be in parts of the Southern Hemisphere, such as Central Africa and Latin America, and the root cause of the disorder attributed to ethnic violence, the influence of transnational criminal organizations, or famine. Most Army missions would involve participation in multinational stability operations.

We chose for our illustrative scenario a multinational effort to restore order to Bogota, Colombia, led by the U.S. Army. This would follow extensive and debilitating urban conflict between rival Colombian drug cartels. After the warring parties have agreed to a cease-fire and been separated, the multinational force would deploy to Bogota to enforce the cease-fire.

In general, U.S. Army involvement would include using light infantry, Special Forces (SF), and aviation to control the buffer zone established to separate the warring parties.

In addition, U.S. forces, working alongside allied units, would have to begin to disarm the drug cartels, collect intelligence on their whereabouts and intentions, and be prepared to defeat them if the cease-fire fails.

We postulate that the drug cartels might possess small numbers of current-generation artillery and mortars as a well as UAVs converted to unsophisticated cruise missiles through the addition of conventional warheads.

Major Competitor Rising/ Caspian Scenario

- Features of this Future
  - Single power or bloc challenges the United States across the board
  - Develops significant conventional and strategic nuclear capabilities, including power projection and space; leverages RMA
  - Prepare to fight multicorps-size ground wars in two theaters simultaneously
- Features of this Scenario: Sino-Russian entente confronts U.S./NATO
  - Russia invades former Soviet Caucasus republics (Azerbaijan, Georgia, etc.)
  - United States seeks to protect Western access to Caspian oil
- U.S. Concept of Operations
  - Combat forces stationed in the theater in peacetime
  - Blunt Russian offensive with long-range artillery/rockets and tactical air power
  - Reverse Russian gains with armor and attack helicopter task forces
- AMD Threat: second generation
  - ICBMs, TBMs, and cruise missiles
  - FW and RW aircraft, UAVs
  - MRLs, artillery, and mortars

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This is the first of our medium-good worlds, which incorporate a mixture of good and medium trends in the five areas of interest. In this future, labeled Major Competitor Rising, the United States is faced with the prospect of a single power or bloc challenging it across the board. This competitor could project conventional power, maintain robust strategic and conventional capabilities, and exploit the revolution in military affairs (RMA). Faced with such a threat, the U.S. Army would need to be prepared to fight multicorps-size ground wars, potentially in two theaters at the same time.

In a scenario reminiscent of ones used in the Army After Next and Transformation war games conducted by TRADOC at the Army War College, we chose a Sino-Russian entente as the major competitor to illustrate the military challenges in this world. This entente would be a marriage of Russian combat power and Chinese technology, financing, and political support. The Sino-Russian entente would attack the oil-rich portions of the Caspian region, and the United States would feel compelled to protect Western access to Caspian oil. At the same time, the entente would make a secondary thrust against U.S. allies in the Balkans.

To counter the rise of the entente, the United States had already stationed significant forces in the theater in peacetime. These forces are designed to provide deterrence and the initial defense against a Russian attack, using long-range artillery and rockets as well as tactical air power to blunt the Russian armored offensive. The ultimate U.S. goal is to roll back any Russian territorial gains using armored vehicle and attack helicopter task forces.

The threat is this scenario would be formidable. It would include large numbers of technologically sophisticated weapons of all kinds, ranging from mortars to ICBMs.

Competitive Multipolarity/ Iraq Scenario

- Features of this Future
  - Two or three Great Powers arise with military/economic capability comparable to the United States
  - Multisided competitions among defensive alliances for influence in less developed regions
  - Demand for power projection and presence deployments
- Features of this Scenario
  - Iraq disintegrating along religious and ethnic lines
  - Competition for influence between U.S./UK/Japan, Russia/France/India, China/Iran/Saudi Arabia alliances
- U.S. Concept of Operations
  - Rapidly insert capable light mechanized forces into northern Iraq
  - Move south; seize key cities, roads, bridges
  - Coerce rival forces into withdrawing
  - Be prepared for escalation to combat if coercion fails
- AMD Threat: current-generation ICBMs, TBMs, cruise missiles, FW aircraft, UAVs, rockets, and artillery

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Competitive Multipolarity is the name we've chosen for our second medium good world. In this future, two or three large powers are capable of challenging the United States on more or less equal terms. Each of these near-peer rivals builds a coalition of allies and friends, which vies for influence in the less-developed regions of the world. The U.S. military in this world, and the Army in particular, would have the mission of rapidly projecting forces into regions where encroachments of rival alliances endanger American interests. The Army, therefore, would need to meet the demand for power projection and presence deployments.

The illustrative scenario for this future assumes that Iraq is disintegrating along religious and ethnic lines and that the three major alliances—U.S./UK/Japan, Russia/France/India, and China/Iran/Saudi Arabia—are jockeying for position in that troubled nation.

To deter undue influence by any of the other alliances, the United States decides to rapidly insert light mechanized forces into northern Iraq. From staging bases in Turkey, these forces will move south, seizing key cities and other strategic targets. The hope is that this rapid action will force rival coalitions to withdraw from Iraqi territory. Should this tactic fail, however, U.S. and coalition forces would have to be prepared to conduct combat operations.

Although all types of air and missile threats would be represented in this scenario, they would be present in only modest numbers and would be based on technology available today.

Transnational Web/ International Terrorism Scenario

- Features of this Future
  - Transnational distributed actors (e.g., corporations, criminal syndicates, terrorists, special interest groups) rise in power at expense of nation-states,
- Features of this Scenario
  - U.S. kills fossil fuel emissions treaty at UN
  - Radical World Environmental League uses autonomous, Internet-connected terrorist cells to attack U.S. interests around the world
- U.S. Concept of Operations
  - Use cyberintelligence and foreign law enforcement sources to pinpoint cell locations abroad
  - Use cyber public affairs to defeat enemy Web propaganda offensive
  - Deploy SOF teams to attack cell locations abroad
- AMD Threat
  - Current-generation mortars
  - Next-generation MRLs and weaponized UAVs launched from ships

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Transnational Web is our one medium-bad world. In this future, the nation-state has lost a significant amount of its power in international politics. That power has been usurped by globally distributed actors, such as corporations, transnational criminal organizations, terrorist networks, and special interest groups. In this world, it is likely that several major countries will, in effect, be controlled by transnational interests. One could imagine, for example, a future Poland whose government has been completely penetrated and coopted by a globally active Russian Mafia supported by its own mercenaries.

To illustrate challenges facing the Army in this world, we constructed a scenario in which a radical transnational environmentalist group uses the Internet to coordinate terrorist attacks against U.S. embassies, businesses, and tourists on every continent after the United States refuses to sign a new international agreement on reducing fossil emissions.

The U.S. military response to these attacks is to use cyberintelligence and foreign law enforcement sources to pinpoint cell locations around the world and send SOF teams to attack those cells once located. In addition, the United States would mount a cyber public affairs campaign to defeat the enemy's propaganda offensive.

The threat pertinent to AMD in this scenario would be of limited scope, including only mortars, multiple rocket launchers (MRLs), and weaponized UAVs. This last type of weapon, however, which could be launched from merchant ships off the U.S. coast, would cause the most concern in this scenario.

Chaos/Anarchy/ Egypt Civil War Scenario

- Features of this Future
  - Nation-states destroyed in several regions by overpopulation, environmental degradation, ethnic violence, emergence of regional warlords
  - Increase in terrorism, WMD proliferation, mass migrations, disease
- Features of this Scenario
  - Civil War in Egypt between secularists and Islamic fundamentalists
  - Losing fundamentalists launch last-ditch nerve gas attack on Cairo
  - U.S./NATO intervention for humanitarian relief and urban counterinsurgency
- U.S. Concept of Operations
  - Seize key ports and airports in northern Egypt
  - Move ground forces into Cairo and seal off infiltration routes into city
  - Distribute humanitarian aid, repair urban infrastructure, and decontaminate key facilities
- AMD Threat
  - Current-generation MRLs, artillery, and mortars
  - Next-generation weaponized UAVs

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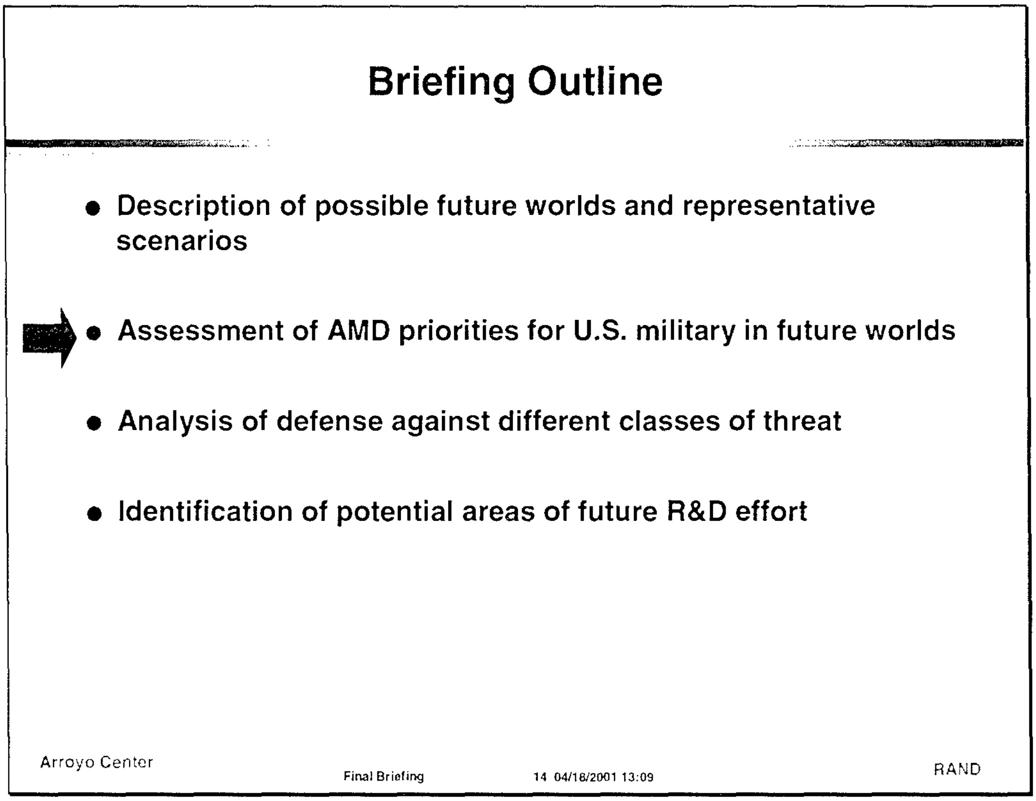
Chaos/Anarchy represents the worst-case world, one in which trends in all five areas are unfavorable to U.S. interests. In this future, the nation-state again loses considerable power. However, this time we see power devolving down to subnational actors. The premise of Chaos/Anarchy is that such factors as overpopulation, environmental degradation, and ethnic strife cause the collapse of the nation-state in large swaths of the developing world. The resulting vacuum is filled by warlords who, lacking a tax base, turn to terrorism and the smuggling of contraband, narcotics, and weapons of mass destruction (WMD) to support their "regimes." This is a world of massive instability that frequently witnesses mass migrations and virulent epidemics as well as fierce communal violence involving increasingly sophisticated weaponry. Terrorist attacks by various subnational groups against major Western cities ("have-nots" attacking the "haves") become disturbingly common. Clearly, the national security threats posed to the United States in this world—by virtue of their diversity, scope, and often shadowy quality—would be more difficult to grapple with than those present in the previous five alternative futures.

An Egyptian Civil War is the centerpiece of the scenario selected to illustrate the complexities of this worst-case world. We constructed a situation in which this civil war between Islamists and the secularists concludes with an Islamist nerve gas attack on Cairo. In response, the U.S. Army leads a multinational effort to restore order in the devastated city. Specifically, the Army has a twofold mission: conduct humanitarian relief, and carry out urban counterinsurgency operations against the remaining Islamist guerrillas.

In particular, U.S. forces would first need to seize key seaports and airports in northern Egypt. Next, ground forces would need to move into the city and seal off infiltration routes. Having done that, coalition forces would then proceed to distribute humanitarian aid, repair urban infrastructure, and decontaminate key facilities.

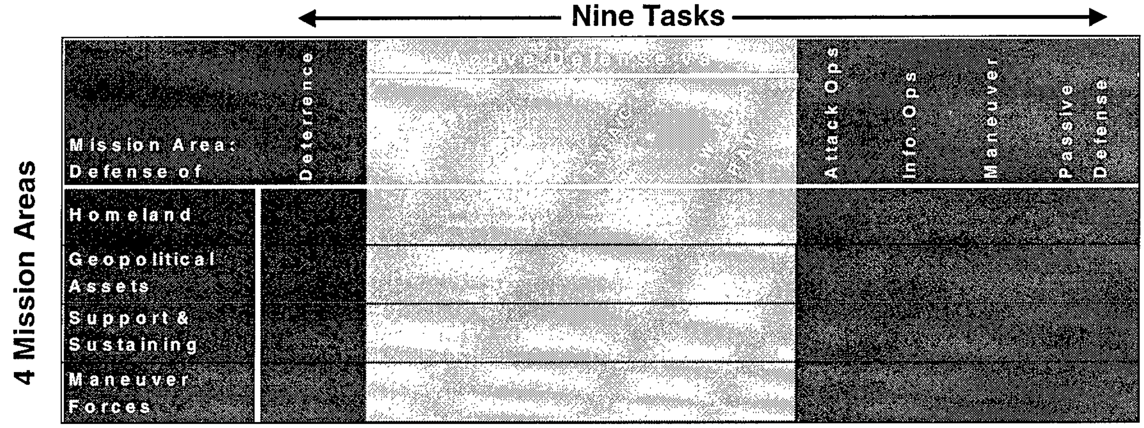
The threat in this final scenario represents the type of weapons that might be in the hands of fundamentalist guerillas. This would include MRLs, artillery, and mortars based on current technology, as well as next-generation UAVs equipped with warheads.



The next step in our analysis was to identify those AMD tasks critically important in each of the scenarios just described.

Extend Prior Work on Future Worlds to Focus on AMD Missions and Tasks

Considered full range of AMD threats from mortars to ICBMs



FW = fixed-wing aircraft
RW = rotary-wing aircraft
CM = cruise missiles
RAM = rockets, artillery, and mortars

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We extended RAND's earlier work on possible future worlds by establishing a framework that we could use to examine the needs for AMD in the postulated worlds.[2] We considered the full spectrum of AMD applications—ranging from defense against rockets, artillery, and mortars (RAM) to defense against cruise missiles and UAVs to national defense against ballistic and cruise missiles.

To carry out our analysis we first divided the AMD mission into four major mission areas of homeland defense, defense of geopolitical assets, defense of support and sustaining facilities, and defense of maneuver forces. These four mission areas, which are listed in the left-most column of the figure above, are meant to be broad and generic in nature so that they can be evaluated in all postulated futures and scenarios. Homeland defense would involve protecting all assets in the United States from aerial attack of any kind—missiles, bombs, rockets, etc. Defending geopolitical assets encompasses protecting nonmilitary assets in foreign countries, such as allied capitals, or such geostrategic targets as oil fields or important waterways. Defending the support and sustaining facilities would involve protecting staging bases, such as airports and seaports, as well as rear areas and logistics assets in a theater of war. Finally, defending maneuver forces would entail protecting combat troops in the field.

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[2]This framework was not included in RAND's previous work on future worlds. Rather, it is the result of original research in this project.

We also defined nine tasks that represent activities that might be performed in carrying out the four missions defined above. These nine tasks, listed above the columns in the chart, include both active and passive means of defense, as well as tasks both directly and indirectly related to AMD. Again, these tasks were meant to be generic so that they could be applicable to all worlds and scenarios. Deterrence refers to the ability to deter air and missile attacks by fielding an effective defense. The four active defense tasks would provide protection from attacks by ICBMs, TBMs, fixed-wing aircraft and cruise missiles, and, finally, helicopters and RAM. The final four tasks represent alternative ways of defeating air and missile threats, including attacking launchers, denying the enemy information on the location of friendly assets using both passive and active means, fast-paced maneuver to prevent targeting, and passive protections of assets. For each of the scenarios previously described, we ranked the relative importance of each of the nine tasks to the implementation of each of the four major missions. We assigned each task a score from 1 to 4, with 1 representing a task critical for that mission area and 4 for tasks that were unnecessary or would not contribute. In this way, we hoped to identify tasks likely to be critical in a variety of scenarios that capture the wide range of challenges that Army AMD might face in the future.

The next three figures present examples of the evaluations of the importance of the defense tasks in the various scenarios. We chose to discuss scenarios from worlds 1, 3, and 6 in detail because they demonstrate the effect that widely varying futures might have on air and missile defense needs. A summary of the results of the evaluations of all six scenarios follows the three examples.

Matrix for Unipolar World (Indonesia Scenario)

1 = Critical

n/a = not applicable

4 = Not beneficial or not needed

Mission Area: Defense of	Deterrence	[illegible]	[illegible]	[illegible]	[illegible]	Attack Ops	Info Ops	Maneuver	Passive Defense
Homeland	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Geopolitical Assets	1	n/a	[illegible]	[illegible]	[illegible]	2	2	4	1
Support & Sustaining	4	n/a	[illegible]	[illegible]	[illegible]	2	2	3	1
Maneuver Forces	4	n/a	[illegible]	[illegible]	[illegible]	2	2	1	3

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The first scenario postulates an Indonesian land grab and provides an example of how we assessed the relative importance of the various tasks.

In this example, Indonesia does not threaten the United States itself with attack nor does it possess any ICBMs. Thus, the homeland defense mission area and the task of defending against ICBMs are not applicable to this scenario.

Indonesia does threaten the capital of Malaysia with ballistic and cruise missiles, however. Consequently, deterring such attacks and defending against them should they occur are critically important. Thus, the tasks of deterrence, active defense versus TBMs and cruise missiles, and passive defense are judged critically important to the geopolitical asset mission area. Of less importance to this mission are attack operations against missile launchers and information operations to disrupt Indonesian command and control. Because of the relatively long distances between Indonesia and Malaysian cities, defense against helicopters and RAM was considered unnecessary to the protection of geopolitical assets. Finally, maneuver operations are not an option for geopolitical assets.

Similar reasoning was used to assess the importance of the various tasks to the remaining two mission areas. When protecting the sustaining base or maneuver forces, active defenses against cruise missiles, manned aircraft, and RAM become critically important. At the same time, maneuver operations, rather than passive defense, become a means of mitigating the effects of enemy attacks on maneuver forces. Finally, the Indonesians would have multiple means for attacking the sustaining base and maneuver forces—including short-range cruise missiles, rockets, and artillery—because of their proximity to Indonesian territory. As a consequence, it is unlikely that even effective defenses against such attacks would be able to deter them.

Matrix for Major Competitor Rising
(Caspian Scenario)

1 = Critical n/a = not applicable

4 = Not beneficial or not needed

Mission Area: Defense of	Deterrence		Attack Ops	Info. Ops	Maneuver	Passive Defense
Homeland	1		3	3	4	2
Geopolitical Assets	1	n/a	2	2	4	2
Support & Sustaining	4	n/a	2	2	3	3
Maneuver Forces	4	n/a	1	1	2	3

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Provision of active defenses becomes critical to more mission areas when facing the large and varied threat present in the scenario involving a Russian attack on the Caspian region. In this example, Russia can threaten the United States with ICBMs, so the homeland defense mission is crucially important and both deterrence and active defense against strategic ICBMs are critical. So, too, are the tasks of deterrence and active defense against threats to allied cities included in the geopolitical asset mission area. Furthermore, both the support and the sustaining base and maneuver forces could be subject to attack at all levels, so active protection is critical for them. Finally, attack and information operations and maneuver might be able to mitigate the severity of some of the large and varied attacks.

Matrix for Chaos/Anarchy
(Egypt Civil War Scenario)

1 = Critical n/a = not applicable

4 = Not beneficial or not needed

Mission Area: Defense of	Deterrence	Active Defenses	Attack Ops	Info Ops	Maneuver	Passive Defense
Homeland	3	[illegible]	1	2	4	2
Geopolitical Assets	3	[illegible]	1	2	4	2
Support & Sustaining	4	[illegible]	1	2	2	1
Maneuver Forces	4	[illegible]	1	2	1	1

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In contrast to the previous scenario, the last postulated world would include a much more limited threat. Although this world has been characterized as the most unfavorable to U.S. interests in terms of economic, political, and ecological stability, the AMD threat posed by potential enemies would be rather limited. Furthermore, the military operation included in the representative scenario—restoring order in and decontaminating Cairo after a chemical gas attack—poses less demanding challenges for air and missile defense than previous scenarios.

In this case, attack operations that could preclude terrorist attacks on any class of target are the most critical task for all four mission areas. Critically important active defenses are those against short-range threats, such as rockets and mortars, and against cruise missiles based on weaponized UAVs. In this scenario, such defenses are needed to protect U.S. forces operating in the city and the support and sustaining base. Finally, maneuver would also be critical for denying the enemy the ability to target maneuver forces.

Number of Worlds in which AMD Task Is Critical (Priority = 1)

Misson Area: Defense of	Deterrence					Attack Ops	Info. Ops	Maneuver	Passive Defense
Homeland	2					2	1		
Geopolitical Assets	3		3	4		1			1
Support & Sustaining			3	6	5	1			3
Maneuver Forces				5	5	4	3	5	1

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This chart summarizes the number of worlds in which each task is ranked as critical for a particular mission area. (Each of the entries in the matrix represents the number of worlds in which the task is critical.) The task of deterrence, for example, is critical for defending the homeland and geopolitical assets in three or fewer worlds (primarily in worlds 3 and 4).

An examination of critical tasks across all of the scenarios that we postulated shows that most tasks other than active defense are critical only in certain circumstances or for a limited number of missions. In contrast, with the exception of defense against ICBMs, active defenses are critical to two or three mission areas in at least three of the worlds and scenarios postulated by RAND.

Several tasks are critical in many worlds, but only in the defense of maneuver forces. This may be because there are so many types of threats to the maneuver forces—artillery, rockets, aircraft, UAVs, etc.—and it is important to employ several means to defeat them all. Relevant tasks for protecting maneuver forces, in addition to active defenses, include maneuver, information operations, and such attack operations as counterbattery fire.

Critical Active Defense Tasks Vary Across Worlds

H = Homeland; G = Geopolitical; S = Support & Sustaining; M = Maneuver Forces

World	Active Defense vs			
	ICBMs	TBMs	FW & CMs	RW & RAM
U.S. Unipolarity	H G S M	H **G** **S** M	H **G** **S** **M**	H G **S** **M**
Democratic Peace	H G S M	H G S M	H G **S** **M**	H G **S** **M**
Major Competitor	**H** G S M	H **G** **S** **M**	H **G** **S** **M**	H G **S** **M**
Multipolar World	**H** G S M	H **G** **S** M	H **G** **S** **M**	H G **S** **M**
Transntn'l Web	H G S M	H G S M	**H** **G** **S** **M**	H G **S** M
Chaos/Anarchy	H G S M	H G S M	H G **S** **M**	H G **S** **M**

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A closer examination of active defenses in the six worlds shows how their importance varies across worlds.

The matrix in this figure is set up differently than the previous ones. The six worlds, rather than the major mission areas, are listed in the left-most column. The four active defense tasks are listed across the top. Highlighted in each box of the matrix are those mission areas—defense of the homeland, geopolitical assets, the support and sustaining base, and maneuver forces—for which each task, such as countering ICBMs, is critical in each of the six worlds. For example, in the first world, U.S. Unipolarity, defeating ICBMs is not critical to any of the mission areas; defeating TBMs is critical to protecting geopolitical assets and the support and sustaining base; defending against fixed-wing aircraft and cruise missiles is critical to protecting everything except the homeland; and active defense against attack helicopters and RAM is critical to defending the support and sustaining base and U.S. maneuver forces. A similar summary of the missions for which each type of active defense is critical is presented for each of RAND's postulated worlds.

A summary of the types of threat present in each of the six scenarios is presented on the next slide.

Threats Vary by Scenario

	World/Scenario					
	1	2	3	4	5	6
Threat	Indonesian Land Grab	Colombian Drug Cartels	Russian Attack on Caspian	Dispute over Control of Iraq	International Terrorism	Egyptian Civil War
ICBMs (vs US)			X	X		
TBMs	X		X	X		
Cruise Missiles	X	X	X	X	X	X
Fixed Wing	X		X	X		
Rotary Wing			X			
Reconnaisance UAVs	X	X	X	X		
MRLs	X	X	X	X	X	X
Artillery	X		X	X		
Mortars	X	X	X	X	X	X

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The provision of different types of active defense varies across the worlds and associated scenarios in part because the type of threat present in each scenario differs. This figure summarizes the types of threat that air and missile defenses would face in the six different scenarios. The threats, ranging from ICBMs to mortars, are listed on the left. It should be noted that weaponized UAVs, which represent a very unsophisticated type of cruise missile, are included under the heading of cruise missiles.

Only three scenarios—those in worlds 1, 3, and 4—represent conventional war. The other three scenarios include operations other than war (OOTW), which are more suited to the worlds that they illustrate. As a consequence, theater ballistic missiles (TBMs), which are not likely to be a threat in OOTW, are evident in only three of the scenarios. Similarly, fixed-wing aircraft present a serious threat in only three scenarios, the same ones that include TBMs. Furthermore, because only two worlds postulate rivals with significant military capability, the threat of ICBMs is present in only two scenarios.

On the other hand, cruise missiles are present in all scenarios. Although the presence of large numbers of cruise missiles, or ones based on sophisticated technology, is limited to the same scenarios that include TBMs, unsophisticated versions based on UAVs could be present in small numbers in any of the scenarios. Finally, the threat from mortars and MRLs is also likely to be present in all of the scenarios.

Critical Tasks for U.S. Air and Missile Defense

- **Countering ICBMs in Defense of Homeland**
  - Critical only in worlds with major competitors
  - Capacity required related to world situation
- **ATBM Defenses Critical to Protection of**
  - Geopolitical assets in conventional conflicts
  - Sustaining base and Maneuver Forces versus peer competitor
  - All but Maneuver Forces versus international terrorists
- **Cruise Missile Defense Critical to Protection of**
  - Sustaining base
  - Maneuver Forces and geopolitical assets in several worlds
- **Defense versus RAM Critical to Two Missions**
  - Affected least by state of world or type of conflict
  - Protection of Sustaining Base and Maneuver Forces
- **Attack Operations, Information Operations, and Maneuver: Critical in most worlds to protection of Maneuver Forces**

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The broadest observation that we draw from our analysis is that defenses against ballistic missiles are critical in fewer worlds than active defenses against cruise missiles or rockets, artillery, and mortars. In fact, defenses against ICBMs are critical only in those worlds that include major competitors. ATBM defenses are primarily critical to the protection of geopolitical assets in worlds where conventional conflicts are likely and to the protection of the support and sustaining base in high-intensity conflicts. Active defenses against cruise missiles, however, are critical to the protection of the support and sustaining base in all of the scenarios that RAND analyzed.

Defense of maneuver forces requires the performance of several different tasks to provide robust protection. Because the threat is so varied, a combination of active defense against attack helicopters, rockets, artillery, and mortars—often referred to as Short-Range Air Defense (SHORAD)—attack operations, such as counterbattery fire; information operations; and maneuver are critical to limiting damage to maneuver forces.

Briefing Outline

- Description of possible future worlds and representative scenarios
- Assessment of AMD priorities for U.S. military in future worlds
- Analysis of defense against different classes of threat
  - Defense versus TBMs
  - Defense versus cruise missiles
  - Short-range defense
- Identification of potential areas of future R&D effort

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The next section will discuss the analysis of issues concerning the provision of air and missile defense in the future, as illustrated by the six scenarios. We focused our analysis on those critical active air defense tasks identified in the various scenarios. We did not investigate issues pertaining to homeland defense against ICBMs because such analysis is sufficiently distinct and extensive to warrant separate treatment outside of this analysis. Our analysis will, therefore, be presented in three sections addressing, in turn, defense against TBMs, defense against cruise missiles, and issues pertaining to short-range defense against manned aircraft, UAVs, artillery, and rockets.

By using a model of ATBM system capability developed during a previous RAND study, this project was able to analyze defenses against TBMs in detail. The model, which simulates interceptor capability against TBMs of varying ranges, allowed the project to conduct detailed and quantitative analysis of the capabilities of the various proposed ATBM systems in specific scenarios. In contrast, the lack of a parallel modeling capability versus cruise missiles or short-range threats precluded the analysis of their defense in equal depth.

Initial Assumptions for TBM Analysis

- BMC4I
  - All systems interoperable and working
  - All information available instantaneously
- All programmed AMD systems available in quantity and perform to specifications
  - THAAD
  - Patriot (PAC-3) and /or MEADS
  - Navy Theater-Wide
  - Navy Area Defense
- Airborne laser not analyzed or modelled explicitly
- Effect of countermeasures treated parametrically

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We made several initial assumptions regarding U.S. and threat systems in order to conduct our analysis of defenses against tactical ballistic missiles.

First we assumed that U.S. forces enjoy perfect battle management, command, control, communications, computers, and intelligence (BMC4I). That is, all relevant systems are assumed to be in place by 2020 and working as designed. As a consequence, information sharing is instantaneous and flawless.

Next, all programmed AMD systems, to include the Army's Theater High-Altitude Area Defense System (THAAD), Patriot with the Advanced Capability-3 (PAC-3) missile, and Medium-Range Enhanced Air Defense System (MEADS), as well as the Navy's Theater Wide (NTW) and Area Defense (NAD) systems, were assumed to be available in the planned quantities and performing up to specifications.

However, we did not model the Air Force's airborne battlefield laser system in detail.

Finally, it is likely that countermeasures to either the BMC4I network or the AMD systems themselves would be present in some of our illustrative scenarios. To capture the effects of such countermeasures, the ability of the BMC4I network to provide information and the effectiveness of individual air defense systems themselves were treated parametrically. By doing so, we hoped to capture the effects of countermeasures without modeling them explicitly.

Assumed ATBM Sensor and Tracking Capabilities

- **Autonomous:**
  - **Target above horizon**
  - **Within uncued range of radar**
- **Space-Based Cuing:**
  - **Cue provided shortly after target booster burnout**
  - **Detection range double that of uncued radar**
- **Space-Based Tracking:**
  - **Track initiated following booster burnout**
  - **Target track data provided to interceptor throughout target flight**

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We assumed that three different levels of sensor and tracking information were potentially available to the defensive systems. The most limited is that resulting from the autonomous tracking capability of the radar associated with the system itself. In this case, the target must be five degrees above the radar horizon and must be within the uncued range of the radar before tracking can be initiated. This would also correspond to a scenario in which countermeasures had disabled the C4I network and prevented passage of information from space-based assets to AMD systems.

An intermediate level of sensor and tracking information assumes that the system's autonomous radar is cued by a generic space-based asset. By reducing the sector of the sky over which the detection radar must search for its target, we assumed that space-based cuing would double the uncued range of the autonomous radar.[3] The earliest that such a cue could be provided would be after the burnout of the threat missile's booster.

The highest level of sensor and tracking information would be represented by the ability to track the threat missile continuously from space after booster burnout.

[3]The doubling of the radar's range with space cuing was an assumption made by the authors and not based on any specific radar characteristics. Such an assumption does not necessarily reflect the Army's assessment of what the actual impact of space cueing would be on the performance of specific ATBM radars.

Characteristics of Model

- Various characteristics of interceptor included
  - Min intercept altitude
  - Max intercept altitude
  - Burnout velocity
  - Min closing velocity
  - Max look angle
  - Max crossing angle at intercept
  - Min flyout time to intercept

- Interceptors launched 15 seconds after track initiated
  - Space tracking: tracking begins at booster burnout
  - Autonomous and cued radar: tracking begins
    - After threat booster burnout
    - After missile above radar's 5 degree elevation horizon
    - Within detection range

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We used a RAND model developed previously to identify issues pertaining to defense against TBMs.[4] The model takes several characteristics of the air defense interceptor into account, such as minimum and maximum intercept altitude, minimum closing and burnout velocity, maximum look angle and maximum crossing angle at intercept, and minimum time allowed for flyout to intercept.

In all cases, the missile must be tracked continuously for a minimum of 15 seconds before the interceptor is launched. The point at which track is initiated depends on the assumed level of sensor support, which could be either autonomous radar, space-cued autonomous radar, or space-based tracking.

Using the model, we generated coverage footprints for the various air defense systems against the threat present in those scenarios that included TBMs. [5]

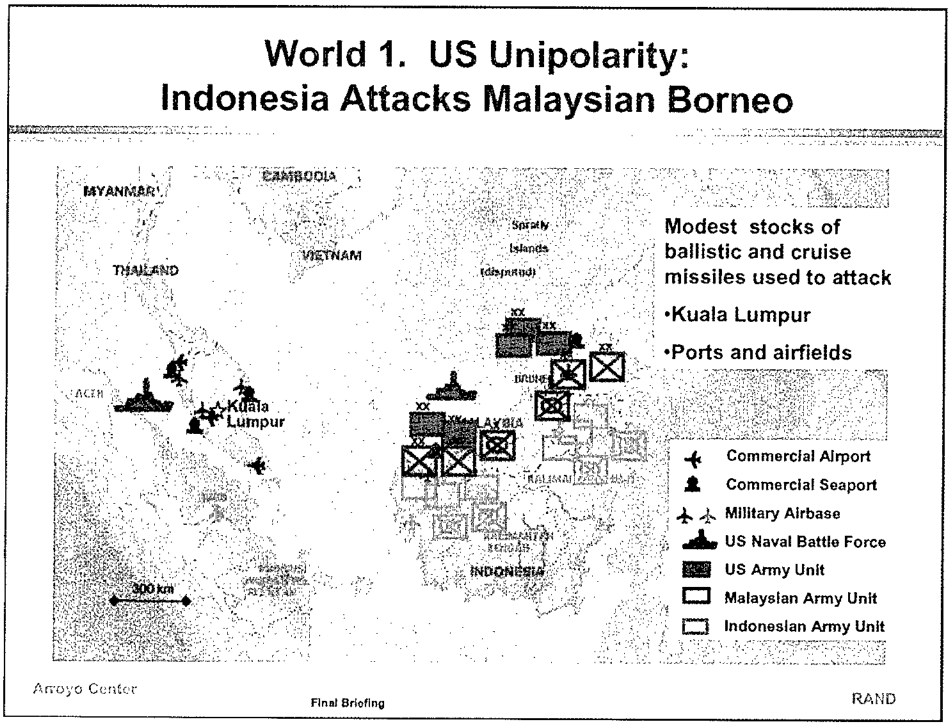
[4]RAND's model has been used in previous studies of ballistic missile defenses.

[5]It should be noted that RAND's model has not been validated by the Army. Nor has the Army verified the data used in the model to define the characteristics of generic threat missiles and ATBM systems. As a consequence, RAND's coverage estimates may differ from those that would be generated by Army models.

Issues Relating to Defense Against TBMs

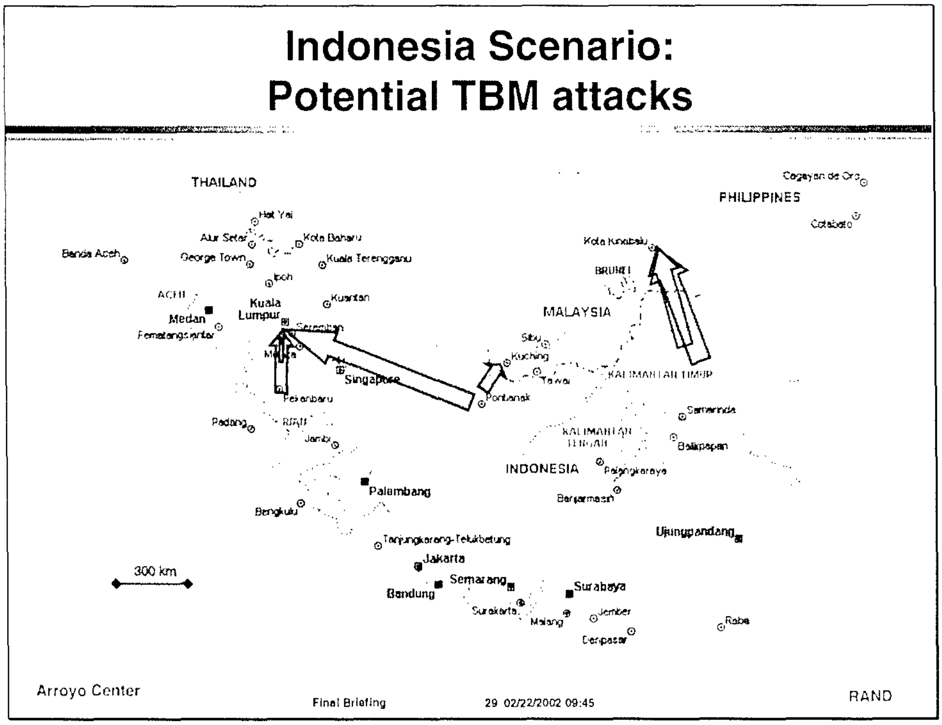
- Coverage of assets in theater
- Protection of allied cities removed from theater
- Effectiveness of defense: minimizing leakage

We identified issues that are of concern when defending against TBMs. These include the ability to provide coverage of assets in theater, the ability to protect allied cities far removed from the theater, and the effectiveness of the defenses in preventing TBMs from leaking through the defensive coverage.



In the illustrative scenario for the first world, U.S. Unipolarity, Indonesia attempts to overrun the Malaysian portions of Borneo with light infantry divisions backed by mechanized brigade task forces. In addition, the Indonesian military mounts a campaign to coerce the Malaysian government into suing for peace and to degrade the airports and seaports that the United States would need to be able to make an effective forced entry into the region. To achieve these ends, Indonesia employs ballistic and cruise missile strikes against key Malaysian government buildings and installations in Kuala Lumpur and major ports and air bases in Borneo.

U.S. objectives would be to halt and reverse the Indonesian advance, restore the territorial integrity of Malaysia, and ensure the viability of the existing friendly regime in Kuala Lumpur. To do this, the U.S. military would have to create and defend lodgments with initial forces airlifted onto Borneo to assist the Malaysian infantry divisions and armored brigades stationed there. Ultimately, Malaysian and U.S. ground forces would mount a counterattack with later arriving heavier ground forces to restore the integrity of Malaysian territory on Borneo.



The potential TBM attacks on Kuala Lumpur and assets on Borneo are depicted on this map. Because the terrain on Borneo is very rugged with much of it either mountainous or swampy, launch sites could be limited to areas with a decent road or rail network. We therefore assumed that launch sites would most likely be near Indonesian military bases or major rail and highway routes.

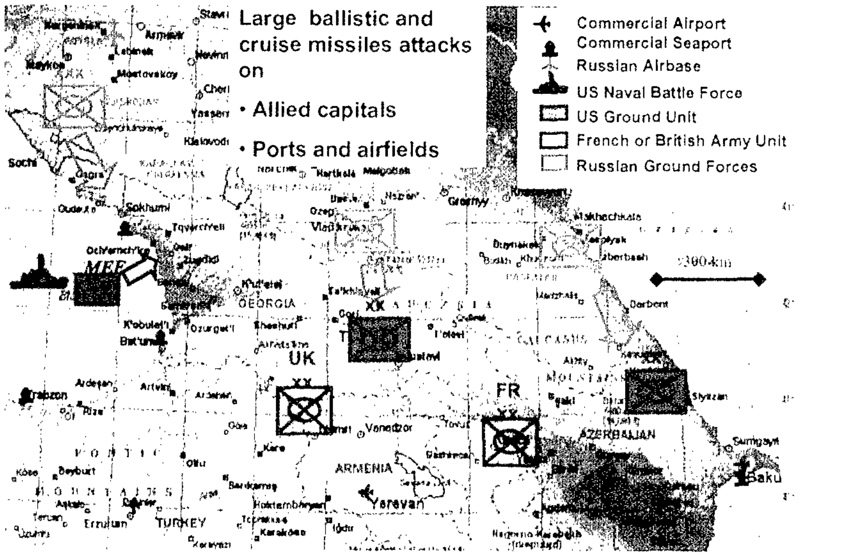
Although we assume that Indonesia does have some chemical warheads for its TBMs, we also assumed that it employs only conventional warheads in its initial attacks against facilities that the United States would likely need to secure a foothold in Borneo.

Protection of Malaysia Provided By Proposed Defense Systems

- THAAD can provide extensive coverage
  - Can defend virtually all Malaysian territory
  - Against threats of varying ranges and launch points
- Patriot can protect area immediately surrounding cities
- NTW coverage limited due to proximity of threat
- NAD can protect important ports and adjacent inland territory

Several observations and insights can be drawn from the coverage capabilities predicted by RAND's model for ATBM systems in this illustrative scenario. One is that THAAD can provide potentially widespread coverage against TBMs launched from several different directions and with varying ranges. Patriot units, if located in cities and equipped with PAC-3 missiles can also provide a robust defense of cities and the areas immediately surrounding them. With respect to the Navy systems, NAD can protect the important ports for the insertion of Army forces in this scenario, as well as adjacent inland territory. Finally, the short ranges from which some potential Indonesian TBMs could be launched in this scenario would allow the attacking missiles to remain within the atmosphere. Because NTW operates only above the atmosphere, it has no capability against such short-range attacks. Thus, its ability to provide coverage of the Malaysian peninsula or much of Borneo is limited.

World 3. Major Competitor Rising
1st Theater: Russian Attack on Caspian Region



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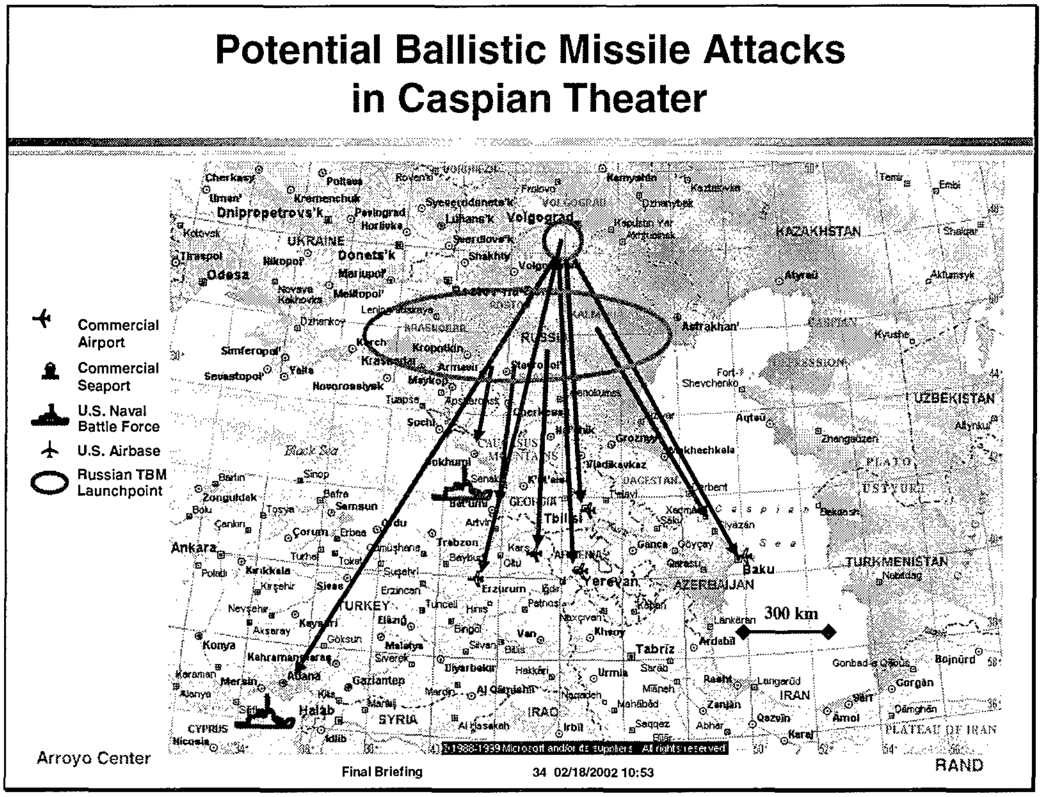
We move next to another scenario that includes the potential of TBM attacks. This is the one associated with the third future world called Major Competitor Rising. The illustrative scenario involves an attack on the Caspian region by a resurgent Russia. The graphic portrayal in this figure depicts three Russian heavy corps mounting a three-pronged attack on Georgia and Azerbaijan. Opposing this attack are two U.S. divisions stationed forward in the Caucasus. The defense is further aided by allied troops—a division each from France and Britain—and a U.S. Marine Expeditionary Force (MEF). U.S. Navy and Air Force units provide additional support.

We assume that Russia possesses vast military resources in this future world. Consequently, we posit that it could launch large ballistic and cruise missile attacks on the ports and airfields in theater, as well as those in nearby Turkey that the United States would need to use as staging bases. In addition, Russia could threaten to attack French and British cities to discourage allied participation in opposing the Russian attack.



Russia could mount potentially large ballistic missile attacks, both in the actual area of conflict and on the staging areas nearby. These include attacks on the ports and airfields in the Caucasus; attacks on the capitals of Georgia, Azerbaijan, and Armenia; and attacks on staging bases in Turkey, including Incirlik Air Base (AB). Providing sufficient defense is complicated by the large areas from which the missile launches might originate, as indicated on the chart.

Protection of Entire Theater Difficult

- Defending all of Turkey could depend on information from space assets
  - Protecting supporting bases and major cities possible with autonomous radars
    - THAAD stationed at Incirlik
    - NTW off coast south of Incirlik
  - Protecting area closer to Russia requires sensor support from space
- Coverage of troops and cities in Caucasus difficult from outside theater
  - Little strategic depth (350 km)
  - ATBM systems provide limited forward coverage
    - Placing THAAD in Caucasus places it at risk
    - NTW in Black Sea risky and not beneficial

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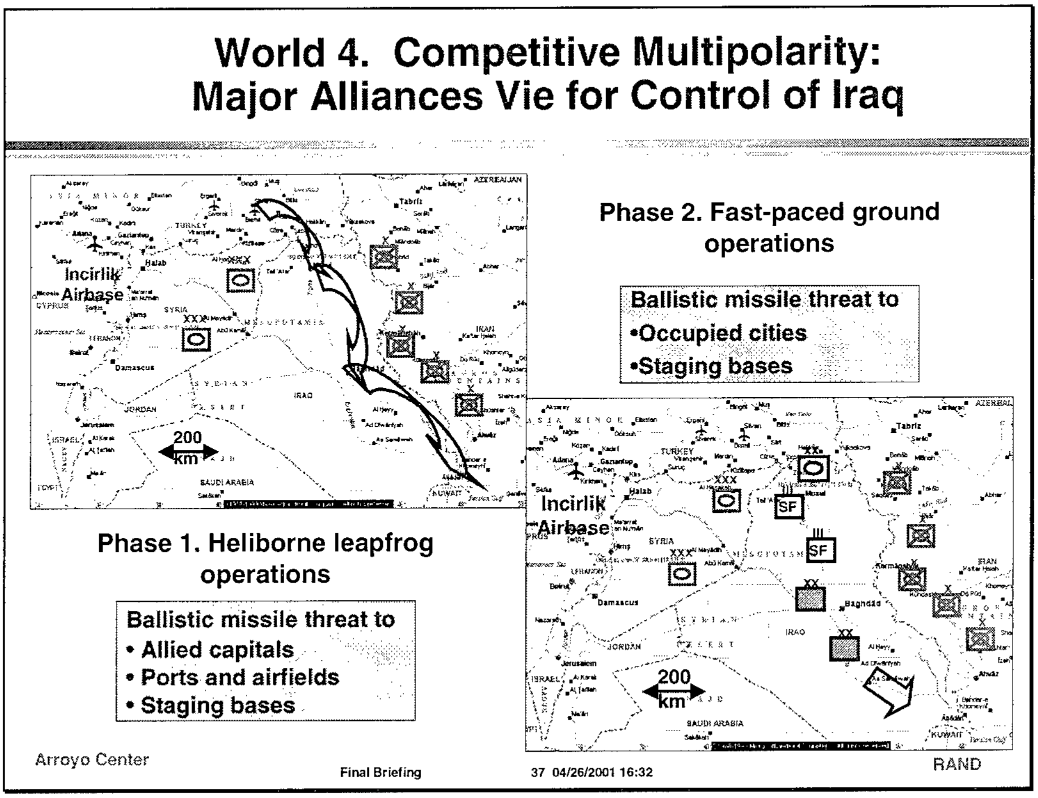
The results from RAND's model of ATBM coverage capabilities indicate that supporting bases and cities in Turkey can be protected by theater-level defenses stationed there or nearby, but protection forward of the interceptor systems requires sensor support from space. In the case of THAAD, cuing can expand the coverage from the area around Incirlik AB, where it is assumed to be positioned, to more than half of Turkey. For a system like NTW, tracking information from space is essential for any coverage beyond its immediate surroundings. With such assistance, however, NTW is potentially capable of defending all threat aim points in Turkey.

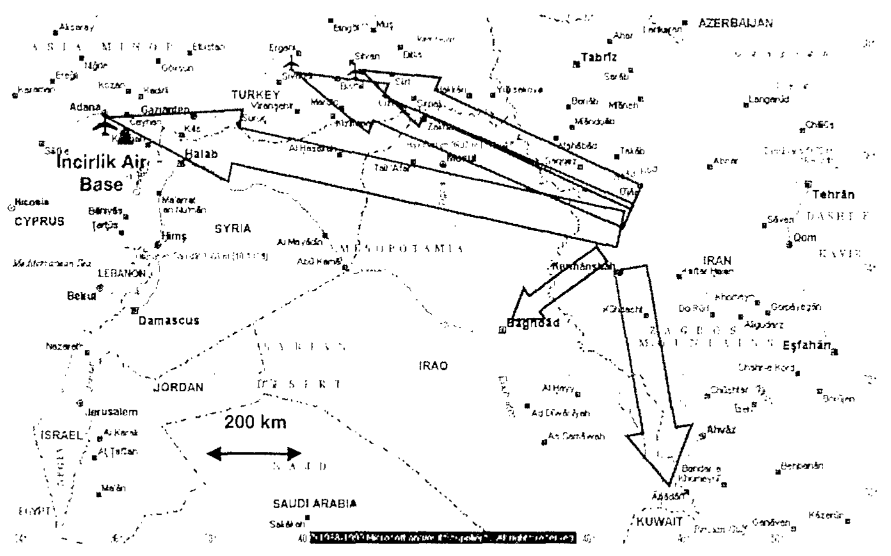
In that same scenario, protection of areas of the Caucasus, such as northern Georgia and Azerbaijan, presents some difficulties because the Caucasus provide very little strategic depth (only 350 kilometers, north to south). THAAD provides much more extensive protection in the rear than forward, but positioning it forward near the border with Russia places it at risk of being overrun. And, even putting the NTW platform at risk by stationing it in the Black Sea close to the coast does not allow it to protect the entire Caucasus region.

This presents commanders in theater with a difficult choice of either providing protection to forward areas, thereby running the risk of missile defense sites being overrun by the enemy, or keeping THAAD in the rear and providing only limited defense for vulnerable forward airfields and troops.



The fourth world, that of Competitive Multipolarity, provides the final scenario that includes TBMs. As the scenario unfolds in this world, three major alliances—one composed of the United States, UK, and Japan; another including Russia, France, and India; and the last, which comprises China, Iran, and Saudi Arabia—are jockeying for position in a disintegrating Iraq. In this world, Syrian and Iranian forces are lined up along the Iraqi border poised to take control of that country as its leadership collapses. U.S. operations would be split into two phases, the first involving heliborne operations to seize the major Iraqi cities. The second phase would consist of fast-paced ground operations involving U.S., British, and Japanese forces to control the Tigris-Euphrates valley and deter action on the part of the Syrians or Iranians.

Potential TBM Attacks



Several types of assets in theater could be subject to TBM attacks from Iran. The first likely targets would be the major reception areas in Turkey, to include Incirlik AB and nearby ports. Subsequently, staging bases in southern Turkey for the heliborne operations might also come under attack. Finally, once cities in Iraq have been occupied by U.S. forces, they too could become targets.

Protection of Assets in Iraq Difficult If Launchers Placed in Turkey

- Protection of staging bases in Turkey feasible
- Protection of US forces in Iraq problematic because systems cannot accompany fast moving troops
  - NTW and NAD limited to waterways
  - THAAD requires significant airlift
  - Patriot requires significant time to break down and set up

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According to the results generated by RAND's models, protecting areas of Turkey should be possible with projected ATBM systems, but extending that protection to U.S. forces in Iraq could be difficult. The reasons for this are twofold. First, as discussed previously, the protection forward of ATBM systems is limited. Second, neither THAAD nor the Navy systems can accompany U.S. forces on quick-moving operations. Navy systems are obviously limited to waterways. THAAD, on the other hand, requires several C-5 sorties to move. Even Patriot, which is transportable, takes significant time to break down and set up, making it incompatible with fast-paced operations.

Issues Relating to Defense Against TBMs

- Coverage of assets in theater
- Protection of allied cities removed from theater
  - Iraqi Scenario example
- Effectiveness of defense: minimization of leakage

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A second issue concerning defense against TBMs is the need to protect allied cities from attack. This task was identified earlier as critical to three scenarios. We chose to use the Iraqi scenario just described to analyze the capability of planned systems to protect geopolitical assets far removed from theater.

In that scenario, Japan and Britain provided forces to help gain control of Iraqi territory. It is conceivable that Iran, which is postulated to possess ballistic missiles with very long ranges in this scenario, would try to disrupt the coalition by threatening Tokyo and London with attack.

Defending London and Tokyo from Iranian Attack Feasible But Information from Space Needed

- **Defense of cities themselves feasible with planned systems and autonomous radars**
- **Protection of surrounding areas greatly enhanced by tracking information from space assets**
  - **THAAD coverage expanded from immediate cities to**
    - **All of Britain**
    - **Most of Japan**
  - **NTW coverage expanded from very limited area with autonomous radar to all of Britain and Japan**

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Results from RAND's model show that defense of both London and Tokyo is feasible with currently planned systems. The capability of those systems would be greatly enhanced, however, by information provided from sensors in space. In the case of THAAD, space cuing would enable launchers in London and Tokyo to defend, respectively, most of Britain but only a limited area in Japan. Space tracking would expand THAAD's coverage to include all of Britain and significant parts of Japan. As for NTW, space-based tracking would enable it to protect large areas encompassing either city. However, if NTW had to rely solely on its autonomous radar, its coverage would be extremely limited.

Because both systems are dependent on information provided by systems based in space, this is an example of circumstances where countermeasures would severely limit the coverage of both systems.

Issues Relating to Defense Against TBMs

- Coverage of assets in theater
- Protection of allied cities removed from theater
- Effectiveness of defense: minimizing leakage
  - Multilayered defenses
  - Countering barrage attacks

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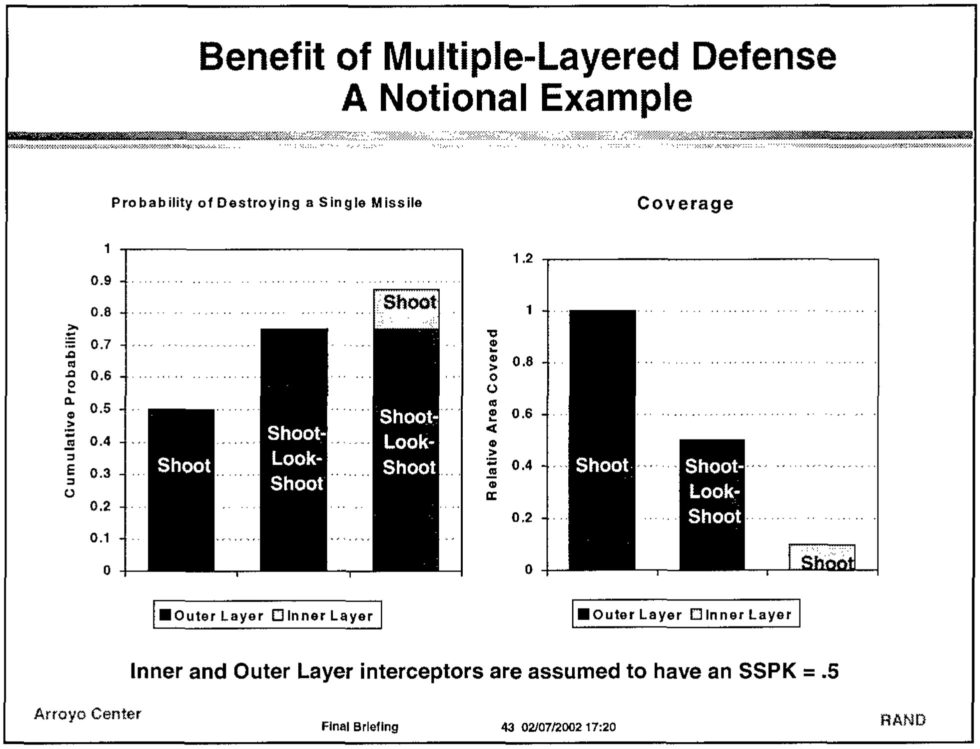
The final issue regarding defense against TBM attacks that we analyzed was that of the ability of the defense to minimize leakage of TBMs. In exploring this topic further, we chose to examine the benefit that multilayered defenses can provide, as well as how proposed Army systems might counter large barrage attacks.



There is an obvious trade-off between the extent of area covered and the ability to provide a multilayered defense, as is illustrated in this depiction of a notional two-layer defense. Launching more than one defense interceptor against an attacking missile yields significant benefits, as is shown by the chart on the left. It shows how the cumulative probability of destroying an attacking missile with a multilayered system increases with the number of shots or layers. (The individual interceptors of each layer are assumed to have a single-shot probability of kill (SSPK) of 0.5.)

The corresponding coverage of various defensive postures, as depicted in the chart on the right, shrinks as either the number of layers or number of interceptor shots increases. The area that can be protected by a second shot from the outer layer is limited by the delay between the first and the second shot. The coverage afforded by the combined layers is limited by the range of the innermost defensive system. Thus, an extremely effective and robust defense can be provided only over a limited area.

This has important implications for defense against missiles armed with chemical or biological warheads. To prevent leakage of even one warhead requires a highly effective defense, but the ability to achieve this is limited to small areas. Thus, the critical mission of defending high-value and highly vulnerable areas, such as large populations, from warheads containing biological or chemical weapons will require a multilayered defense or one capable of multiple sequential shots.

Barrage Attacks Likely in Caspian Scenario

- Russia able to sustain capability to mount large attacks over several weeks
  - Several hundred MRBM launches per day
  - Several hundred SRBM launches per day
- Multilayered defense may not be feasible
  - Russia also capable of large cruise missile attacks
    - Initial surge of 1,000 cruise missiles fired against ports, airfields, air defense sites, and key command posts in Turkey, Georgia, and Azerbaijan
    - Sustained attacks of 500 cruise missiles per day
  - Patriot batteries dedicated to countering cruise missiles
- THAAD batteries could face large coordinated attacks

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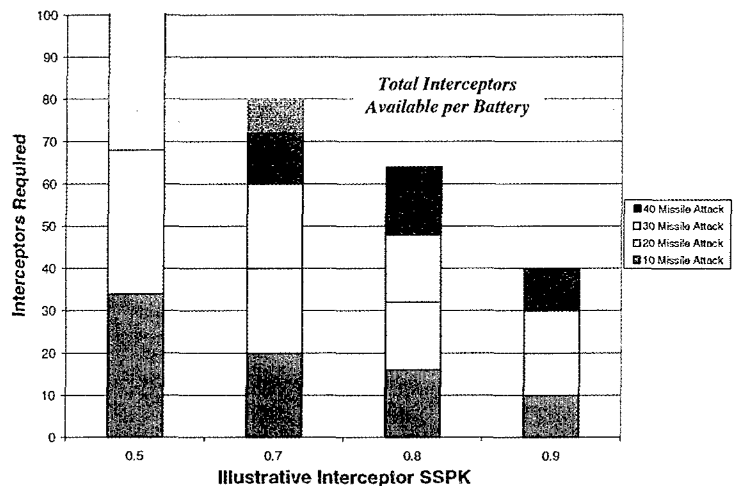
There may be some circumstances in which an enemy might be able to mount very large missile attacks. Such a case is represented by our illustrative scenario involving a Russian attack on the Caspian region. In that scenario, Russia is postulated to launch hundreds of TBMs a day and would be capable of doing so over a protracted period. In addition, Russia would use its large stocks of cruise missiles to attack ports and airfields. By forcing Patriot defenses to concentrate solely on countering cruise missile attacks, Russia would effectively eliminate the U.S. option of a multilayered defense. THAAD batteries would then be faced with large TBM attacks with no backup.

Effective Interceptors Enhance Ability to Defeat Barrage Attack

Number of Interceptors Required to Achieve a 90% Total Probability of Kill Against a Barrage Attack



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ATBM systems such as THAAD should be able to counter barrages of up to 40 missiles if they are equipped with large numbers of highly effective rounds. This chart depicts the trade-offs between the effectiveness of an illustrative ATBM interceptor and the number of those interceptors needed to destroy 90 percent of attacks of varying sizes, ranging from 10 to 40 missiles. For example, it shows that more than 80 ready interceptors with an SSPK of 0.7 would be needed to defeat 90 percent of a 40-missile barrage. Indeed, more than 100 interceptors with SSPK = 0.5 would be needed to destroy 90 percent of a 40-missile attack. Conversely, only 40 very effective interceptors with an SSPK of 0.9 would be needed against the same size barrage.

This type of illustrative analysis demonstrates that THAAD batteries will need to have large numbers of highly effective ready rounds if they are going to be able to counter large barrage attacks.

Observations Concerning TBM Defense (Based on Three Scenarios)

- **Coverage in theater**
  - Systems provide complementary coverage
    - THAAD: extensive coverage versus wide range of threat missiles
    - NTW : potentially wide-area versus long- and medium-range missiles
    - NAD: ports and surrounding area
    - Patriot: high-value assets (e.g., airports)
  - Reliance on space-based information (SBI) varies
    - THAAD:
      - Significant autonomous coverage
      - SBI can extend envelope forward
    - NTW:
      - Little autonomous coverage
      - SBI needed to exploit capabilities of interceptor
    - Patriot and NAD:
      - Radars and interceptors well matched
      - SBI provides little added benefit

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We can make several observations concerning issues related to defense against TBMs based on our analysis. The first set of observations pertains to the coverage offered by the postulated defense systems. In general, the four systems that have been proposed offer complementary coverage. Navy systems, such as NAD, are capable of protecting areas near ports, with potentially much broader coverage offered by NTW. It should be noted that NTW cannot counter very short-range missiles. This shortcoming is overcome by THAAD, which can provide quite extensive coverage versus missiles of widely varying ranges. Finally, Patriot equipped with PAC-3 missiles can offer robust point area protection of high-value assets, such as airports, wherever they are.

The four proposed systems vary, too, with respect to their reliance on and benefits from tracking information from space. The lower-tier systems, NAD and Patriot, because the range of their interceptors and capabilities of their autonomous radars are well matched, benefit little from additional information from space. This makes them less vulnerable to certain countermeasures, such as attacks upon space assets or the C4I network. NTW, however, provides very limited coverage if it must rely on its autonomous radar to track threat missiles. It needs information from space-based assets, specifically full trajectory tracking, to provide extensive coverage. Finally, although THAAD can extend its coverage forward by using information from space-based interceptors, it still retains the ability to provide significant coverage relying on its autonomous radar alone. Thus, countermeasures against space-based assets would diminish coverage but not totally negate it.

Observations Concerning TBM Defense (cont'd)

- **Coverage in theater cont'd**
  - **THAAD needed in theater early**
    - **NAD cannot protect inland targets**
    - **NTW cannot defend areas against short range missiles**
  - **Mobile or easily transportable Army missile defense system needed for fast moving scenarios**
- **Protecting allied cities far from theater: level of coverage depends on sensor information**

	Autonomous Radar	Space Tracking
• THAAD	Cities	Wider area
• NTW	Little if any	Very wide area

- **Minimizing leakage**
  - **Multiple layers best, but coverage limited by shortest-range system**
  - **Highly effective interceptors can reduce risk of exhaustion of ready rounds in large missile barrages**

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Additional points can be made regarding coverage against TBMs. The first is that THAAD is needed in theater early to provide capabilities that no other system can. These include protecting large inland areas, intercepting missiles far from the asset being protected, and defending against short-range missiles. These capabilities are particularly important when the defenses must counter missiles potentially equipped with chemical or biological warheads. In such cases, interception at long range ensures that the missile will be destroyed before it can deploy countermeasures and that dangerous debris falls far from the asset being protected. The second point is that if the Army is going to engage in fast-paced ground operations, it needs an anti-TBM system capable of moving with the maneuver forces.

When it comes to protecting allied cities far removed from the theater of operations, THAAD and NTW represent trade-offs in capability. If information from space is available, NTW offers the broadest coverage. If such information is not available because of countermeasures or technological or programmatic infeasibility, then NTW would provide very limited coverage. Meanwhile, THAAD would retain the ability to protect the city and surroundings based on its autonomous radar.

The final observations pertain to the issue of minimizing leakage of enemy TBMs. The most effective way to limit the number of leaks is to provide a defense of multiple layers. But, because the innermost layer is of limited range—that associated with Patriot—the extent of such coverage would also be limited. Furthermore, highly effective interceptors can reduce the number of rounds needed to counter large missile barrages, thereby reducing the risk that a system's ready rounds will be exhausted by a single barrage.

Briefing Outline

- Description of possible future worlds and representative scenarios
- Assessment of AMD priorities for U.S. military in future worlds
- Analysis of defense against different classes of threat
  - Defense versus TBMs
  - Defense versus cruise missiles
  - Short-range defense
- Identification of potential areas of future R&D effort

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The next section will investigate issues pertaining to cruise missile defense.

Assumptions in Cruise Missile Analysis

- Perfect BMC4I
- Elevated sensor (e.g. JLENS) available to provide detection and tracking data to ground based systems
- Range of interceptor missiles treated parametrically
- Do not address issues of
  - Lethality
  - Saturation
  - Exhaustion

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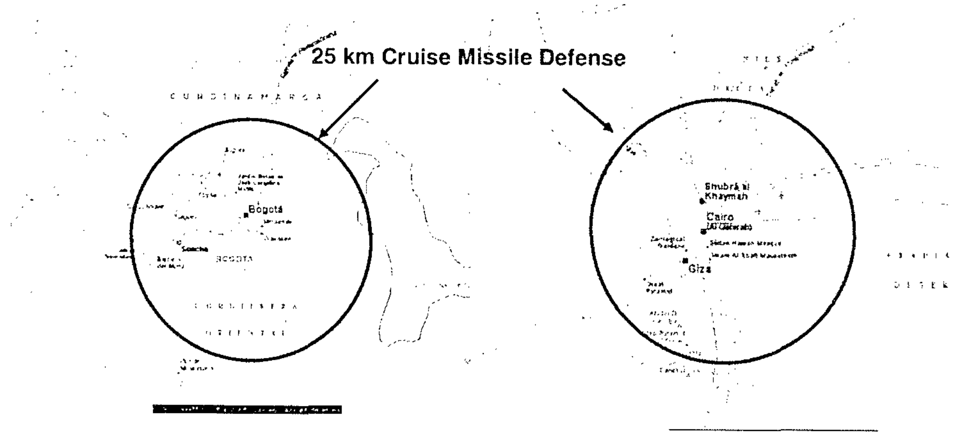
We made several assumptions in the course of performing our analysis. First, as in the analysis of TBM defense, we assumed perfect BMC4I. We assumed that an elevated sensor, such as the Army's Joint Land-Attack Cruise Missile Defense Elevated Netted Sensor (JLENS), was available to detect and track attacking cruise missiles. The JLENS program is developing sensors that would be mounted on platforms, such as balloons or aircraft, that would operate at altitudes up to 15,000 feet. From this height, the sensors could detect and track even very low altitude cruise missiles at ranges out to 250 kilometers.

We did not model the capability of proposed interceptors against cruise missiles. Rather, we treated the range of generic interceptors parametrically. Finally, we did not examine the lethality of interceptor missiles or related issues of saturation or exhaustion of postulated systems, such as Patriot, MEADS, or NAD.

Protection of Small Areas Against Unsophisticated Foe Should Not Be Difficult

World 2. Democratic Peace
Separate Warring Drug Lords

World 6. Chaos/Anarchy
Pacify Islamic Fundamentalists



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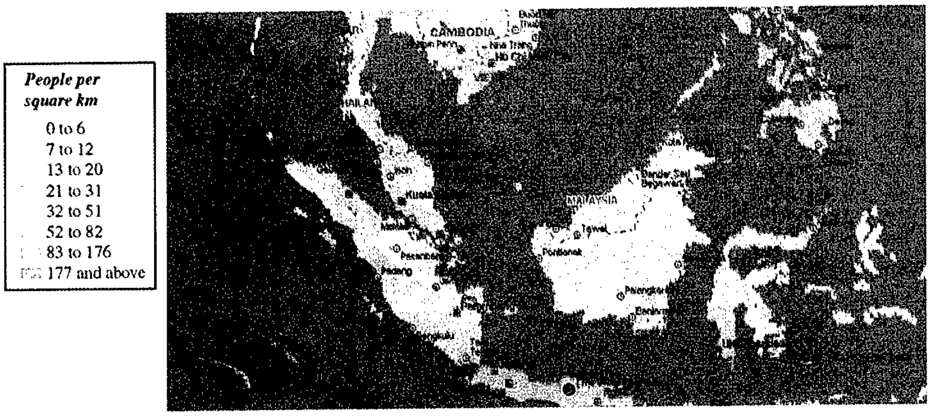
We again used the illustrative scenarios to examine the ability of the systems to provide coverage against cruise missiles. In the case of those scenarios in which operations are confined to a small area—Bogota in World 2 and Cairo in World 6—provision of defense against small attacks of unsophisticated cruise missiles should be feasible for such a system as Patriot or MEADS. Even if the effective range of the interceptor is limited to 25 kilometers, it would still be able to defend the urban areas in question and the adjacent airport.

In Indonesian Land-Grab Scenario, Malaysian Peninsula in Greatest Need of Protection

Population Density of Indonesia and Malaysia



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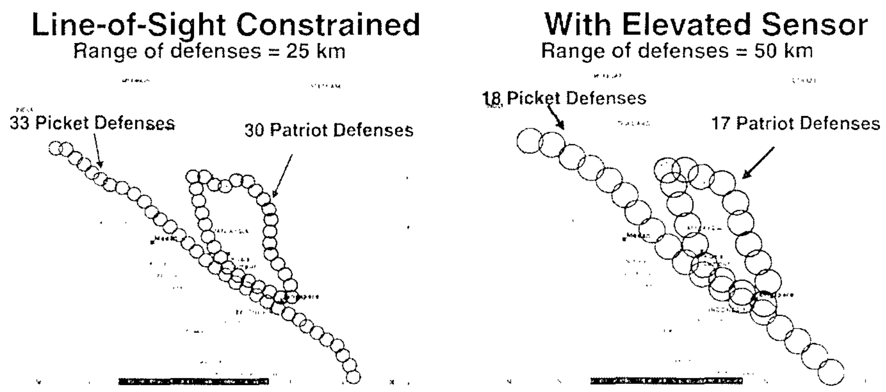
The scenario involving Indonesia, however, presents a situation in which extensive coverage might have to be provided. In the scenario in question, Indonesia retains modest stocks of cruise missiles and uses them primarily to attack air and seaports. It might also use them, however, to attack population centers and infrastructure targets to discourage Malaysia from pursuing its campaign. As is evident from the map, the most densely populated areas of Malaysia are not on Borneo, but are on the peninsula, which is almost uniformly densely populated. Thus, requirements for cruise missile defense could extend to the entire peninsula.

Cruise Missile Defense of Malaysian Peninsula Could Require Large Numbers of Systems



- Cruise missiles have a range of 1,000 Km
- Cruise missiles can be launched from any point on the Sumatr a Coast
- Maneuver ability of cruise missiles forces picket defenses t o extend far out into the Indian Ocean

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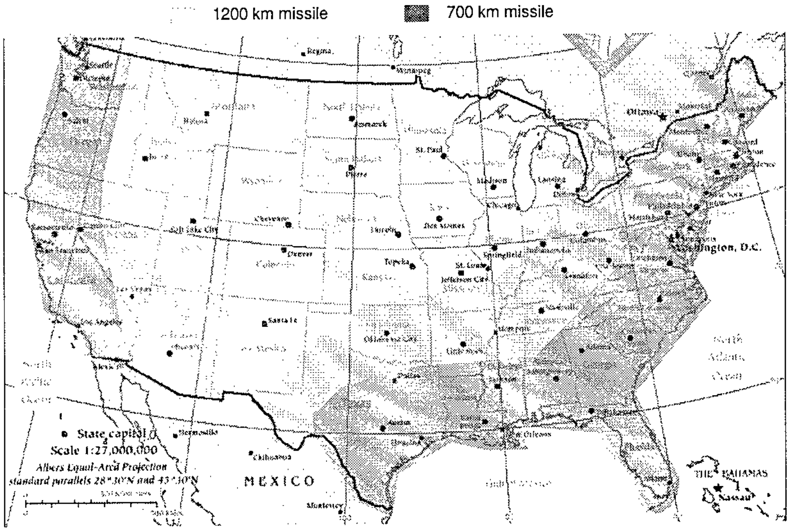
Defending an area as large as the Malaysian peninsula could require significant numbers of defense systems, regardless of whether they are sea-based or land-based. We examined two strategies for defending the peninsula. One would set up a picket line of ships to intercept cruise missiles launched from the Indonesian island of Sumatra. The other strategy would ring the borders of the Malaysian peninsula with interceptor systems. Neither strategy would be favored if the interceptor missiles have equivalent ranges; in each case similarly large numbers of launchers are required.

The presence of an elevated sensor, however, could extend the interceptor range from 25 kilometers to 50 kilometers or more and cut the required number of defensive systems by half.

World 5. Transnational Web/ International Terrorism Scenario: CONUS Areas at Risk from Ship-Launched Cruise Missiles



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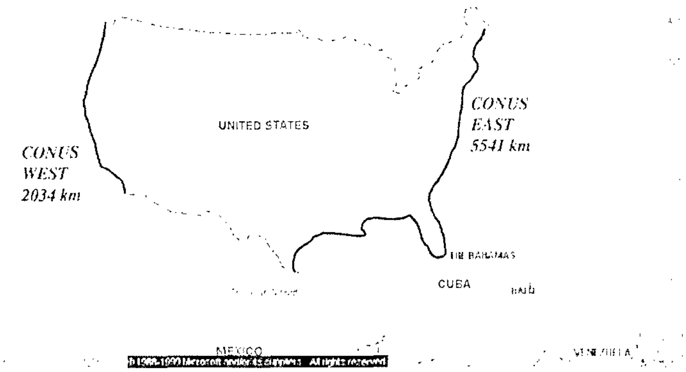
We examined issues related to cruise missile defense in one additional scenario, that associated with World 5 and representing international terrorism. (The two remaining scenarios involved issues of numbers of systems to provide adequate coverage and saturation similar to the issues in the Indonesia scenario, so we did not analyze them explicitly.) In this scenario, we postulated that terrorists might threaten CONUS with launch of rudimentary cruise missiles from merchant ships off the coast. Depending on the range of the missiles, such attacks could threaten the most populous sections of the United States.

Defending Entire CONUS Coastline Would Be Costly

- Need approximately 75 ground sites with a range of 50 km each (or 150 sites with a 25-km range) to defend east and west coasts of the United States

•Augmented by 15 JLENS



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Defending against such cruise missile attacks would be difficult. If land-based systems are the primary means of defense and intercept range is limited by line-of-sight to roughly 25 kilometers, up to 150 sites would be needed to protect the entire coastline. The addition of several elevated sensors—up to 15 JLENS with a tracking range of 250 kilometers—would be needed to enable intercept beyond line-of-sight. Doing so, however, could extend the intercept range to 50 kilometers and reduce the number of missile defense sites to 75. The requirement to field and maintain even this less extensive network, however, would be costly.

Cruise Missiles Likely to Be a Threat in All Geopolitical Futures and Operations

- **JLENS or similar system needed**
  - Extends range of intercept
  - Reduces number of ground sites needed
- **Unsophisticated cruise missiles pose unique challenge**
- **In conventional war scenarios**
  - Threaten access to ports and airfields
    - Navy may be able to protect ports
    - Air entry essential to rapid deployability in Chief's vision
  - Attacks with large numbers possible
  - Requirements for effective Army defenses
    - Easily deployable
    - Large number of ready rounds
- **Need to defend large areas in some scenarios implies need for**
  - Long-range (at least 50 kilometers) interceptor
  - Large numbers of launchers
  - Cooperation between the Army and Navy

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Several observations can be drawn from the previous discussion of cruise missile defenses. The first is that cruise missiles are a likely threat in all situations. This being the case, the most striking need is for an elevated sensor, such as JLENS, to extend the range of intercept beyond line-of-sight. This would reduce the number of defensive sites needed, and it would also extend the keep-out range against missiles equipped with unconventional warheads.

Next it should be noted that simple and unsophisticated cruise missiles based on UAVs pose a unique challenge. Their slow speed and low cruising altitude make them very difficult for Air Force sensors to detect and fighters to destroy.[6] Some defense analysts have postulated that such cheap and unsophisticated weapons are likely to proliferate in the next two decades. Dennis Gormley speculated that an adversary could amass an arsenal of several hundred first-generation cruise missiles by 2010.[7] The combination of large numbers and relative invulnerability to U.S. Air Force defenses makes unsophisticated cruise missiles a likely target for Army and Navy AMD systems.

In scenarios involving conventional conflicts, cruise missiles would threaten access to ports and airfields. Only Army systems would be capable of protecting inland airfields and access to those airfields is crucial to rapid deployability. Furthermore, if facing a major competitor, attacks in large numbers could be possible. These two observations point to the need for an easily deployable Army system with large numbers of ready rounds.

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[6]See John Stillion and David Orletsky, *Airbase Vulnerability to Cruise-Missile and Ballistic-Missile Attacks*, MR-1028-AF, RAND, 1999, pp. 15–17.
[7]Dennis Gormley, "Hedging Against the Cruise Missile Threat," *Survival*, Vol. 40, No. 1, Spring 1998.

Finally, some scenarios call for the defense of large areas. If the Army is to provide such defense, it will need a system capable of long-range intercept and large numbers of launchers. In some areas, cooperation and coordination with Navy systems might reduce the burden on Army defenses.

Briefing Outline

- Description of possible future worlds and representative scenarios
- Assessment of AMD priorities for U.S. military in future worlds
- Analysis of defense against different classes of threat
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  - Short-range defense
- Identification of potential areas of future R&D effort

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The final section of the discussion of our analysis will address issues related to the provision of short-range air defense.

Assumptions Pertaining to SHORAD Analysis

- Needed to protect Support and Sustaining Base and Maneuver Forces
- UAVs, rockets, and mortars always present; scenario independent
- Fixed- and rotary-wing aircraft present only in conventional war scenarios (three of six)

As with the analysis of other types of defense, several assumptions or conditions underlay our analysis of short-range air defense. In general, SHORAD is most critical to protecting the support and sustaining base—including lodgments, depots, and supply nodes—and maneuver forces. Several types of threats relevant to SHORAD were present in all six of the scenarios we investigated. These included UAVs, rockets (from multiple rocket launchers), and mortars. On the other hand, manned rotary- and fixed-wing aircraft posed a threat only in those scenarios that represented conventional conflicts. (These occurred in only three out of the six scenarios.)

Desired Characteristics of Systems to Counter Threats

System Characteristic	FW Aircraft	RW Aircraft	UAVs	Rockets	Artillery	Mortars
Interceptor						
Long-range	X	X	X			
Fast				X	X	X
Cheap			X	X	X	X
Platform						
Covert	X	X				
Cheap	X	X	X	X	X	X
Survivable	X	X	X	X	X	X

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Optimally, SHORAD systems would have different characteristics to counter different threats. For example, to defeat manned aircraft, be they fixed- or rotary-wing, a SHORAD interceptor would need to maximize its range to destroy the aircraft before it launches its ordnance. The SHORAD platform should have a low radar signature so it cannot be detected by the aircraft pilot and avoided in flight.

For use against unmanned targets—UAVs, rockets, artillery, and mortars—the interceptors need to be available in large numbers to counter threats that attack in large numbers. To make large stocks of ready rounds possible, they should also be cheap. UAVs, whether reconnaissance or weaponized, should be intercepted at long range to prevent them from performing their mission. It is often not possible to intercept the remaining three threats—rockets, artillery, and mortars—at long range. But because these threats travel at high speed, effective interceptors would also have to be fast.

Against all threats, fielding large numbers of launchers would yield the greatest coverage and most robust protection. This would be more likely if the platforms are cheap. Finally, because SHORAD platforms need to be deployed in forward areas, they need to be survivable.

Desired Characteristics of Systems to Counter Threats

Typical of missiles

Typical of lasers

Threat

System Characteristic	FW Aircraft	RW Aircraft	UAV	Rockets	Artillery	Mortars
Interceptor						
Long range	X	X	X			
Fast				X	X	X
Cheap			X	X	X	X
Platform						
Covert	X	X				
Cheap	X	X	X	X	X	X

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Unfortunately, no single type of SHORAD system encompasses all of the characteristics desirable to counter all of the potential threats. Traditionally, the mission has been performed with guns and missiles. The Army no longer fields any antiaircraft guns and currently deploys only the Stinger infrared missile to provide short-range air defense. Stinger's characteristics, and those of missiles in general, are highlighted on the slide. Missiles, compared to other options for SHORAD, have a relatively long range, can be fielded covertly, and require relatively inexpensive platforms.

Lasers have recently come under consideration for the SHORAD mission. They have the potential advantages of low cost per kill, if the expense of only the laser fuel is taken into account, and of intercepting targets at the speed of light.

There are, of course, both advantages and drawbacks associated with each technology.

Issues Concerning Use of Missiles for SHORAD

- Infrared-guided missiles
  - Effective versus FW aircraft
  - Less effective versus RW aircraft
  - Relatively cheap and easy to proliferate
- Radar-guided missiles
  - Effective versus both FW and RW
  - More expensive than IR missiles
- Both types vulnerable to countermeasures
  - Low observables
  - Active countermeasures
- Current missiles too slow and expensive for use versus rockets and artillery

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Missiles have successfully performed the SHORAD mission against manned aircraft for decades. Extending their capability against faster and more numerous targets, such as rockets, could prove difficult, however.

The most prevalent SHORAD missiles are guided by the infrared emissions from threat aircraft. They are effective against both fixed-wing and rotary-wing aircraft, although less so against the latter. Their biggest advantage is that they are relatively cheap and easy to proliferate on the battlefield.

Radar-guided missiles can be effective against both fixed- and rotary-wing aircraft and are affected less by weather and cheap countermeasures. They are, however, more complex and expensive than IR missiles.

Because of the long history of SHORAD missiles and their success in the past, militaries worldwide have worked hard to reduce their effectiveness against friendly aircraft. As a result, modern aircraft that incorporate stealth features reduce the effectiveness of both IR and radar-guided SHORAD missiles. Furthermore, more sophisticated foes will also employ active measures to counter SHORAD missile seekers. Overcoming these countermeasures will increase the cost of current-generation systems.

Although missiles can be effective against manned aircraft and some UAVs—and will continue to be so for the foreseeable future—they are not likely to be useful against such targets as rockets, artillery, and mortars. In general, such targets are too fast and too numerous to allow the practical use of missiles to destroy them.

Issues Concerning Lasers for AMD

- **Most promising versus UAVs**
  - Sensor vulnerable
  - Slow vehicle in small numbers ⇒ long timelines (>100 seconds)
  - Relatively soft target
- **Artillery and rocket barrages much more difficult**
  - Harder targets
  - Time lines very short
    - 22 rockets in 44 seconds ⇒ 2 seconds / rocket
    - 54 artillery shells in 60 seconds ⇒ 1 second / artillery shell
  - Time to destroy targets with current technology much longer
    - 14 seconds for rockets
    - 9 seconds for artillery
  - Need several fold factor of improvement in power of laser to meet timelines of barrage
- **Need to reduce size of current THEL by a factor of 10 to achieve a tactical system**
- **Adversely affected by weather and other atmospheric conditions**

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Laser weapons, which use light to blind or destroy, hold the potential to be effective against targets difficult to destroy with missiles. Although light would travel almost instantaneously from the ground platform to the target, the light beam would have to dwell on the target with sufficient intensity and for enough time to deposit energy sufficient to damage or destroy the target. Of the three types of likely targets for laser weapons—UAVs, rockets, and artillery or mortars—UAVs would be the least challenging. First, UAVs would require the least amount of energy to defeat. The sensors on reconnaissance UAVs are very sensitive to light and could be easily damaged or destroyed. UAVs without sensors would also be vulnerable because a laser could damage and potentially explode their fuel tanks. Second, because most UAVs travel at relatively slow speeds, a laser weapon would have ample time to irradiate and damage or destroy them.

In contrast, rockets and artillery or mortar shells present much more challenging targets for lasers. All three are very difficult to damage. (A rocket's motor will have burned out by the time it is within range of a laser weapon.) Furthermore, all would be traveling at speeds 10 to 20 times faster than UAVs and arriving at rates of every one or two seconds. Consequently, to counter a barrage, a laser weapon would need to deposit large amounts of energy on these targets in one or two seconds.

Comparisons to a laser AMD system currently under development—the Tactical High-Energy Laser (THEL)—provide a yardstick with which to measure the level of improvement necessary to counter artillery and rocket barrages. THEL is being jointly developed by the United States and Israel to defend against potential Katyusha rocket attacks from southern Lebanon. To destroy rocket or artillery shells, THEL requires dwell times on the order of 9 to 14 seconds. Thus, an improvement of about an order of magnitude would be needed to meet desired timelines. In addition, THEL is housed in

several trailer-sized modules and requires a great deal of setup time and logistical support. This would not be a problem for a scenario in which the location of likely rocket attacks is relatively fixed (as was the case in Israel when the program was initially conceived). However, a tactically practical laser capable of being deployed and transported along with the maneuver forces it was designed to protect would have to be an order of magnitude smaller than the current THEL.

One final concern with lasers is their susceptibility to atmospheric conditions. Laser light of appropriate wavelength will transmit well through the atmosphere under dry, clear, and calm conditions, such as the conditions in northern Israel where THEL is scheduled to deploy. However, conditions that reduce visibility below 23 kilometers will also reduce the amount of laser light that will reach a target. (Transmission at a range of 5 kilometers in 5-kilometer visibility is 67 percent of that at the same distance with 23-kilometer visibility.) Turbulence in the atmosphere typical during much of the day will further degrade the capability of a laser to deliver energy on target by 50 percent to 90 percent. Finally, any kind of adverse weather—including rain, fog, or snow—will essentially negate a laser weapon's effectiveness.

Best Strategy for SHORAD: Field Complementary Systems

- SHORAD missiles needed to counter manned aircraft
  - USAF may not always totally negate threat: Enemy air defense network capable of defeating USAF is potential future asymmetric threat
  - Longer-range Army AMD busy with TBM and cruise missile threat
  - Troops outside AMD umbrella
  - Synergistic effect of large numbers of covert air defense systems, such as Stinger
    - Forces enemy aircraft up to higher altitude
    - Easier for USAF to defeat
    - Reduces effectiveness of ground attack
- Laser systems
  - Greatest potential against UAVs
  - Technological breakthrough needed versus rockets and artillery
  - Weather and technological risks versus all threats

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Because it is unlikely that a single type of system will be effective against all types of threat that could be encountered in 20 to 25 years, the Army's best strategy for providing short-range AMD would be to field complementary systems. There are many reasons to continue to field SHORAD missiles that are effective primarily against manned aircraft. First, although the U.S. Air Force may be capable of defeating most enemy aircraft, there may be circumstances in which it will not be totally successful. Potential enemies, having seen the power of the USAF demonstrated in the past 10 years, may develop effective Integrated Air Defense Systems. Indeed, RAND has identified such a strategy as a potential asymmetric response to U.S. military prowess.[8] The Army's longer-range air defense systems capable of destroying enemy aircraft (e.g., Patriot and MEADS) could be occupied with the ballistic and cruise missile threat, or Army troops could be deployed outside their coverage.

A final argument for continuing to field such systems as Stinger is the synergistic effect they can have in conjunction with USAF assets, even if they are never fired. The threat of numerous covertly deployed short-range missiles forces attacking aircraft to remain at altitudes above the SHORAD's ceiling. (This was the response of U.S. aircraft to the possible presence of IR SHORADs in Kosovo). This degrades the ability of those aircraft to attack and destroy targets on the ground and makes them easier targets for U.S. fighter aircraft.

In conjunction with its SHORAD missile systems, the Army could seek to develop a laser air defense weapon to counter other types of targets less easily destroyed by

[8]John Matsumura, Randall Steeb, Ernest Isensee, Thomas Herbert, Scot Eisenhard, and John Gordon, *Joint Operations Superiority in the 21st Century*, DB-260-A/OSD, RAND, 1999, p. 10.

missiles, including UAVs, rockets, artillery, and mortars. It must be recognized that, of these, UAVs pose the least challenge and that a technological breakthrough would be needed to yield an effective tactical laser weapon against the other three. Finally, even having achieved such a breakthrough, laser weapons would still need to overcome the effects of bad weather and other atmospheric conditions.

Summary of Observations Regarding Various Types of AMD

- Cruise missile defense and SHORAD needed in all worlds and types of operations
  - Cruise missile defenses
    - Needed in theater early to insure access to airports
    - Elevated sensor essential
  - Presence of SHORAD can yield synergistic effect
    - Force FW aircraft to higher altitudes
    - Defeat of UAVs degrades enemy artillery and MRLs
- TBM defenses important only in worlds where conventional war is likely
  - THAAD needed in theater early
  - Mobile defense needed

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Before identifying R&D efforts that the Army should pursue to prepare AMD for 2020, we need to summarize the main observations we can make regarding conduct of AMD in the future. The first observation is that the need for cruise missile defense and SHORAD is constant across all worlds and scenarios. This is because, regardless of the type of operation, the U.S. Army will need early access to airports, which can be threatened even by unsophisticated cruise missiles available to drug lords and terrorists. Elevated sensors will be needed to defeat those missiles at long ranges.

Similarly, SHORAD will be needed to counter FW aircraft when present and UAVs under almost all likely conditions. Forcing FW aircraft to higher altitudes and denying the enemy information gleaned from UAVs can degrade the enemy's ability to attack U.S. assets effectively.

The need for defense against TBMs depends on the likelihood of conventional war in the future. In worlds where such war is unlikely, the need for TBM defenses is not high. In those futures, however, where the United States might be involved in conflicts with rogue states or a peer competitor, TBM defenses will be needed in theater early. Furthermore, if U.S. ground forces are going to engage in fast-paced maneuver operations, they will need an anti-TBM system that can keep up with them.

Briefing Outline

- Description of possible future worlds and representative scenarios
- Assessment of AMD priorities for U.S. military in future worlds
- Analysis of defense against different classes of threat
  - Defense versus TBMs
  - Defense versus cruise missiles
  - Short-range defense
- Identification of potential areas of future R&D effort

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Based on our analysis of various types of air and missile defenses, we were able to identify several areas where the Army might profitably focus its R&D efforts.

General Observations and Summary Recommendations

- Increased Investment in Cruise Missile Defenses Is Needed
  - Requirement spans futures and operations
  - Develop and field elevated sensors and long-range interceptors in sufficient numbers
- Retain and Improve Short-Range Missile Defenses Versus Aircraft
- Developing Laser Weapons Versus Rockets and Artillery May Not Be Worth the Investment
  - Technological breakthrough needed
  - Effective means of defeating the threat exist, e.g., counterbattery fire
- Planned TBM Defenses Appear Adequate in Most Cases
  - War versus major peer competitor is exception
  - Some futures represent reduced need
  - Steps needed to improve operational utility

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Based on the preceding analysis, several overarching observations and recommendations can be made regarding where the Army should focus its R&D efforts.

The most obvious is the need for increased emphasis on providing cruise missile defense. The cruise missile threat was present in all the scenarios and operations that RAND postulated for the future. Because they can be developed and fielded in the absence of a sophisticated technology base, they could be widespread within 20 years. Furthermore, their ability to fly long distances at low altitude necessitates the development and fielding of both elevated sensors and long-range interceptors to protect large geographic areas or to establish significant keep-out zones.

The Army should retain and improve its missile-based SHORAD capability against manned aircraft, particularly fixed-wing aircraft. These systems are a relatively cheap way to significantly degrade the ability of an enemy to conduct effective ground-attack operations from the air.

Devoting significant amounts of money and effort to develop a tactical laser to destroy enemy artillery and rockets en route may not be worth the investment. Current counterbattery operations are an effective way to defeat or suppress enemy artillery, and fielding of the Crusader will only improve their effectiveness. Therefore, the marginal gain that would accrue from fielding a laser capable of destroying incoming rounds is likely to be small compared to the technological risk involved.

Finally, planned TBM defenses appear to be adequate for almost all the worlds that RAND postulated. The one exception would be the future with a major peer competitor who could overwhelm proposed systems with large barrage attacks. Should that world evolve, greater investment in TBM defenses might be required. On the other hand, some of the postulated worlds would actually result in a reduced need for TBM defenses. Under any circumstances, however, some improvements to planned TBM defenses would increase their ability to provide defense in an operational environment.

The following figures provide more specific observations and recommendations regarding the various types of defenses.

Observations and Recommendations
Regarding ATBM Systems

Observations	Recommendations for R&D
• Need for investment not consistent across all futures	⇒Adjust investment level based on state of world in five years
• THAAD needed in theater early	⇒Develop smaller radars and interceptors
• THAAD logistics burden high	⇒Develop ⇒Radars with lower power requirements ⇒More efficient generators
• Difficult for Patriot to keep up with fast-paced maneuver forces	⇒Develop smaller, more mobile system
• Some potential enemies capable of large barrage attacks	⇒Develop ⇒Very effective interceptor ⇒Launcher with many ready rounds ⇒Cheaper interceptors

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With respect to defenses against TBMs, the Army may want to wait until trends that will define the future become more evident before significantly increasing its investment in such systems. In the meantime, however, it should investigate ways to make THAAD more easily deployable and supportable by developing smaller and more efficient radars and generators. The Army needs to develop a mobile or easily transportable system that can keep up with fast-paced operations. And finally, because a future peer competitor might be able to launch attacks with many TBMs, the Army should seek ways to ensure that the THAAD and Patriot or MEADS interceptors are very effective. It should also develop launchers with large numbers of ready rounds capable of defeating enemy barrage attacks.

Observations and Recommendations
Regarding Defense Against Cruise Missiles

Observations	Recommendations for R&D
• A threat in all worlds and types of operations	⇒ Increase investment in defenses versus cruise missiles
• Capable of low, slow flight	⇒ Develop elevated sensor, such as JLENS
• Cheap GPS-guided versions will proliferate	⇒ Develop radars with 360° coverage
• Could deny access to airports	⇒ Develop easily deployed system
• May need to defend large areas	⇒ Develop long-range interceptors
• Some potential enemies capable of large barrage attacks	⇒ Develop ⇒ Launchers with many ready rounds ⇒ Cheaper interceptors

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Because defenses against cruise missiles are going to be needed whatever the world looks like 20 years from now, the Army should place increased emphasis on developing them. In particular, the Army needs to develop an elevated sensor and organic radar with 360-degree coverage to ensure that those defenses are effective at long ranges. Emphasis should also be placed on making defenses deployable so they can protect airports critical to the opening of a theater. Significant effort should be invested in equipping cruise missile defenses with long-range interceptors so that they can defend large areas with reasonable number of systems. And, as was the case with TBMs, a future peer competitor may be capable of mounting large barrage attacks, and Army defenses will need to have many ready interceptor rounds to counter such attacks.

Observations and Recommendations
Regarding SHORADS

Observations	Recommendations for R&D
• Systems capable of defeating FW and RW aircraft still needed in large numbers	⇒Retain SHORAD missile systems
• Laser AMD weapons require technological breakthroughs	⇒Hedge against failure to achieve technological breakthrough ⇒Improve missiles ⇒Reduce vulnerability to countermeasures ⇒Improve capability in bad weather ⇒Focus laser efforts on defeating sensors and UAVs

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Based, in part, on evidence from the recent air war in Kosovo, we feel that there remains a requirement for and a benefit from the retention of SHORAD systems with capability against manned aircraft. Laser systems seem to have the potential to defeat threats that missiles cannot, such as rockets, artillery, and mortars. However, laser technology is still immature and fielding an effective weapon will require technological breakthroughs. Thus, as a hedge against not achieving those breakthroughs, it would be wise to continue investigating ways to improve the resistance of SHORAD missiles to countermeasures. At the same time, investigations into the feasibility of laser SHORAD systems, particularly against UAVs, should continue.